THE AFFECT OF VARYING AROUSAL METHODS UPON VIGILANCE AND ERROR DETECTION IN AN AUTOMATED COMMAND AND CONTROL ENVIRONMENT

THESIS

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Abstract

This study focused on improving viglance performance through developing methods to arouse subjects to the possibility of errors in a data manipulation information warfare attack. The study suggests that by continuously applying arousal stimuli, subjects would retain initially high vigilance levels thereby avoiding the vigilance decrement phenomenon and improving error detection. The research focused on which methods were the most effective as well the impact of age upon the arousability of the subjects. Further the implications of vigilance and vigilance decrement for correct detections as well as productivity were explored.

The study used a simulation experiment to provide a vigilance task in an reality-based information warfare environment. The results of the study suggest that stimuli type and age do impact arousal, although stimuli type had the greater effect. Also, moderate support was found to indicate that arousal does affect vigilance and vigilance decrement. However, the final analysis revealed that it was the arousal-vigilance interaction that had the greatest impact on correct detection and productivity.

THE AFFECT OF VARYING AROUSAL METHODS UPON VIGILANCE AND ERROR DETECTION IN AN AUTOMATED COMMAND AND CONTROL ENVIRONMENT

CHAPTER 1: INTRODUCTION

Background

"Throughout history, military leaders have regarded information superiority as a key enabler of victory" (JV 2020 2000: 8). The situation has changed little over time. Today's modern military relies heavily upon the instantaneous transmission of volumes of information to coordinate battlefield actions. Weapon systems such as global positioning satellites, cruise missiles, and heads-up-displays in cockpits are some examples of military technologies that rely upon the ability to maintain accurate information flow. The importance of information extends even further when considering the critical nature of reliable communications between commanders and the front lines. To emphasis the importance of information to the military, Joint Vision 2020 states that, "the joint force must be able to take advantage of superior information converted to superior knowledge to achieve decision superiority" (2000: 9).

To combat the advantages afforded by information supremacy, a new type of warfare has evolved called information warfare (IW). In its purest form, IW is simply any aspect of warfare related to gathering, manipulating, or denying information (Schwartau 1994). In this sense, IW is not an entirely new concept. Its foundations can be traced to ancient times when a military commander would use scouts or spies to provide critical information concerning an adversary's capabilities or location. In addition to information gathering, disinformation has been widely used as an IW tactic. In World War II, German commanders were led to believe the attack on

Normandy Beach would actually have happened further east at Calais (Weinberg 1994). In today's context, IW has been extended to include the vast network of computers we commonly call the Internet. While immensely powerful and widely used by the military, the Internet is vulnerable to an IW attack. In many ways, IW has become the "poor man's" weapon of choice as a complex IW attack can be staged from a single computer located nearly anywhere in the world (Schwartau 1994).

Statement of Problem

While IW can take many forms, of particular interest to this study is the practice of manipulating the data the enemy uses for decision making. Data manipulation can occur when an adversary gains access to computers or databases maintained by the military. In this case, the intruder's intent is not to deny service or cause disruption. Rather, it is his or her intent to manipulate or modify the data to cause the system's user to make erroneous decisions based upon the incorrect data (Bizante, Llinas, Seong, Finger, and Lian 2000). For example, if a commander is basing his attack decisions upon a reconnaissance report stating the enemy is just over the next ridge and that data has been modified to show that the enemy is elsewhere, the attack will fail and lives and resources could be lost.

The current dependence of the U.S. military on information necessitates the prompt detection of any altered data. As a result, wide arrays of hardware and software devices have been created to detect and prevent IW attacks. Despite the advanced technology in place today, in many cases it falls to the users of the data to judge the validity of the data provided. Therefore the users must be attuned to the possibility that an IW attack was successful and the data they are examining may be erroneous. Vigilance, as defined by Mackworth (1957) is, "a state of

readiness to detect and respond to certain changes occurring at random times intervals in the environment". User vigilance then may be the key to immediate detection of data manipulation errors. Unfortunately, extensive studies have demonstrated that over time, vigilance will decrease due to a variety of causes (Davies & Tune 1969; Poulton 1977; Singh & Malloy 1993). Such an occurrence has been labeled "vigilance decrement" (Parasuraman 1984: 250). The ramifications of such a defect for the military are significant. Therefore, a method must be developed to increase information technology user's vigilance while limiting the vigilance decrement over time.

Statement of Research

Real-world and laboratory experiments have suggested that human ability to continuously detect errors becomes less reliable over time (Davies & Parasuraman, 1982; Balakrishnan 1998). Consequently, substantial work has been accomplished to try and determine what kinds of factors affect vigilance and how the decrement can be reduced or avoided altogether (Singh and Molloy 1993; Wickens 1999). One concern has been the effect of arousal, or psychophysiological stimulation, towards detection of signals (Paus & Zatorre 1997). Arousal heightens an individual's receptiveness or sensitivity toward some activity. In this situation arousal heightens the operators vigilance or state of readiness to detect an IW attack. According to Parasuraman and Davies, arousal does little to eliminate vigilance decrement (1984). Rather arousal affects the overall level of vigilance. Based on that principle, by continuously arousing an individual to the possibility of data manipulation and thereby continuously maintaining a high overall level of vigilance, his or her vigilance decrement can be theoretically eliminated for a period of time.

In order for arousal to be continually effective, methods must be developed that can be used interchangeably to maintain a high level of vigilance. Mehrabian and Russell (1974) discovered that arousal states can "decrease when situations are simple, unchanging, familiar, and/or predictable". Further, it was found that repeated exposure to the same stimulus would decrease arousal over time (Mehrabian 1995). Therefore, the methods of arousal would seemingly need to be altered as well as their frequency of application.

Research Objectives

If it were possible to make an individual continuously sensitized toward detecting errors, the IW tenant of data manipulation would be greatly hindered (Cohen 1994). The potential benefits to the military's information operations would be dramatic as incorrect or manipulated data would be detected more frequently. Therefore, this research will explore the effects of varying arousal techniques as a method to increase an individual's vigilance or awareness towards detecting incorrect/manipulated data without decreasing the overall effectiveness of the individual's decision making. Using a simulation experiment, varied arousal methods will be applied to subjects performing real-world tasks. The results of the experiment will lead to the development of procedures system designers and information operations personnel could implement throughout the Air Force to defend against information warfare attacks.

Paper Overview

Chapter two contains this study's literature review, which explores previous work accomplished in the vigilance and arousal fields and presents findings relevant to the current study. Of particular concern are the prior studies that included arousal methods as part of the

research, intended or not. Additionally, the literature will lend itself to the development of hypotheses related to the types of arousal most effective in improving vigilance and error detection. The methodology discussed in chapter three provides pertinent information about the sample population chosen for the study and describes the instrument that was used to collect the data. It also discusses the design of the experiment as well as procedures used to analyze the data once collected. A sample of the data collection instrument as well as the questionnaires used is provided. Finally, the methodology chapter discusses steps taken in the actual data collection process. The results of the data analysis are discussed in chapter four and a description of the data is presented. The results are then compared to the hypotheses developed in chapter two. The comparison results are then presented and discussed. Chapter five goes on to summarize the findings of the study and draws conclusions on the results of the data analyzed in chapter four. Recommendations for future related research are also provided in the final chapter.

CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter reviews literature relevant to the study of vigilance performance and possible arousal methods that may influence the error detection aspect of vigilance. This chapter begins with background on how information technology has led to the development of information warfare data manipulation tactics. It then proposes vigilance as a method for defense and discusses its related problems. Arousal is introduced and its effect upon vigilance is explored. Finally, a theoretical model and related hypotheses are developed for the research involved.

Information Technology (IT) in the Military

In the modern age of computers, high-speed telecommunications, and digital everything, the operational environment for the military has undergone considerable change. Even on the battlefield, computer technology can be readily seen either in the form of laptops or the less obvious internal circuitry for fly-by-wire aircraft or state-of-the-art tanks (Webster 1998). Increasingly popular among commanders are automated decision support aids. These tools are designed to bring together large amounts of information and present it in an efficient manner for human decision makers to understand (Fox and Boehm-Davis; DeWaard and Brookhuis 1998). These technologies allow for tremendous increases in productivity and operational capability, however, they also place a large burden upon the information technology to determine what information is important and whether or not it is accurate.

As pervasive as the information technology has become, there seems an endless potential for its use. The Chairman of the Joint Chiefs outlines how the Department of Defense envisions

information technology will be used to gain information superiority over any adversary in the forward looking Joint Vision 2020. He predicts that, "Information superiority will enhance the capability of the joint commander to understand the situation, determine the effects desired, select a course of action and the forces to execute it, accurately assess the effects of that action, and reengage as necessary while minimizing collateral damage." (JV 2020 2000: 22). From this document it is clear the military intends to extract every advantage possible from the information technology available.

Despite the many advantages afforded by information technology, computers alone cannot replace the humans they are designed to aid (Alberts 1996). Instead, a divided role emerges as computers are assigned tasks that are either too difficult or monotonous for humans to perform. In many situations the duties are even shared as humans and computers function as joint monitors for critical processes or even entire systems (Parasuraman 1987). Such interaction requires the operators to have a high degree of understanding of the role and limitations of the computer (Webster 1998). The operator must be able to assume total control of the system in the event of computer failure.

Vulnerabilities of IT

By some estimates, modern computer systems have reached reliability rates spanning from 78% to 95% (Jones 2000). Due to these consistent reliability rates, a tendency to rely upon the information technology to provide completely accurate and reliable outputs develops. Ironically, preliminary studies with National Aeronautics and Space Administration astronaut crews have shown that automated procedural and decision aids have the effect of increasing error rather than reducing it (Mosier et al 1995: 991). Mosier posits "automation commission errors

are errors made when crews do not take appropriate action because they are not informed of an imminent problem or situation by automated aids." (1995: 992). Computer operators can fall into the trap of believing the equipment does not make any mistakes and therefore neglect their shared duty of monitoring the system. In the event of a data error, it is even possible that the operator would ignore it altogether because of their false sense of security in the information technology.

Joint Vision 2020 realizes that information systems, processes, and operations add their own sources of friction and fog to the operational environment (2000: 10). Computers are not all user friendly and many take a great deal of experience and knowledge to operate. In the compressed time and space of a battlefield, any problems that occur with computers often cannot be dealt with appropriately; thereby leading to mistakes in the information they produce. Combine these errors with our ever-increasing dependence on information processes, systems, and technologies and a potential vulnerability arises that must be defended." (JV 2020 2000: 29). For the military this vulnerability is manifested in the realm of information warfare.

Information Warfare as a Weapon

Information warfare, at least as it applies to information technology, is a new facet of the modern defense structure. Joint Vision 2020 defines it as "those actions taken to affect an adversary's information and information systems while defending one's own information and information systems (2000: 26). In an information warfare environment, the information technology structure the military (and society) depends upon to gain advantage will be the target of the attack. The attack methods are widely varied but generally consist of efforts to disrupt, destroy, or deny access to information vital to the enemy's operation. In the information warfare

arena, anyone with a computer or any other form of information technology is vulnerable to attack.

Information warfare is unlike conventional warfare in that it can be waged from relatively safe or remote distances, it costs little to do, and almost anyone (not just a nation-state) can conduct it. The increased availability of the public internet, commercial satellites, and digital communications all give potential adversaries relatively low cost weapons and associated capabilities (JV 2020 2000: 4). Furthermore, these potential enemies are likely to be nontraditional in nature and their application of war. They will often be small groups with limited objectives, yet the damage they could potentially inflict would rival that of the largest land armies. In a 1995 the National Defense University speculated that, while unlikely, an organized information warfare attack focused on the telecommunications, financial, and industrial networks could bring this country "to its knees" faster than a armed invasion short of nuclear war (Libicki 1995: 60).

Data Manipulation

While information warfare can assume many forms, of particular concern to this study is the practice of data manipulation. McCornack's Information Manipulation Theory (IMT) provides critical background on the concept of deception in communications (Biros 1998). Essentially, McCornack argues that the nature of deception falls within how information is manipulated within each message. In a data manipulation environment consistent with information warfare, the method of deceiving the enemy is through distorting the information that is received by the enemy in order to lead him or her into poor decision-making (McCornack 1992). In congruence with IMT, potential adversaries could launch information attacks with the

intent of corrupting data sources as well as the data enroute through the information systems (Bisantz et al 2000). These attacks would be designed to deceive any decision makers relying upon the information by altering in some fashion the content of the information. "An attacker allows the target to continue to operate but manipulates the information the target collects, generates, carries, or analyzes" (Webster et al 1998: 11). The decision maker, dependant upon the automated decision aid in place, could make decisions that are potentially fatal to his or her personnel, or at the very least, give aid to the enemy.

Unfortunately, data manipulation attacks are difficult to detect and are usually conducted without physically compromising the targeted system (Llinas, Bialas, and Chen 1998). Undetected IW techniques could be used to distort information provided to the enemy by their own information and decision aiding systems thereby disrupting their trust in or probable use of such systems. Alternatively, however, one might want to intentionally deceive an enemy with the purpose of having him continue to trust the altered information (Bisantz et al 2000). If the enemy engaging in data manipulation attacks opted for the second option, significant damage could be obtained by convincing the decision maker that the information he or she is using is correct. The attacker could effectively steer the operator into a disastrous situation. The covert methods the attacker uses may allow for repeated manipulation without detection. In the course of a long campaign, such actions could be pivotal in the final outcome of the conflict.

Vigilance as a Counter to IW

Due to the subliminal nature of data manipulation attacks, the role of the human operator becomes greatly elevated. Once the information has been altered, the decision maker stands as the last line of defense to avert the attack if automated detection systems fail (Alberts 1996). The

question then becomes, what can the operator do to detect and alert the decision maker, if different from the operator, to potentially erroneous data? That answer to that question may lie within the field of vigilance research.

N. H. Mackworth defined vigilance as "a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment." (Parasuraman and Davies 1984: 244). This state of readiness implies a certain sustained attention or alertness to specified stimuli, possibly for prolonged periods of time (Dittmar and Warm 1993). Vigilance therefore is a state of awareness within the operator to be able to detect any changes in the data that are not congruent with known or expected outputs. In particular, the operator would be looking for data that does not fit or is not sensible within the context of the operation being carried out. A vigilant operator would focus his or her attention on any subtle change within the system they are responsible for and determine if that change was the result of a data manipulation attack (Paus and Zatorre 1997).

The effect vigilance can have on error detection is critical. Balakrishnan noted that any breakdown in vigilance or sustained attention to the information system in use could cause the operator to overlook or respond too slowly to a mission-critical event (1998). In the case of a data manipulation attack, a vigilant operator may be able to detect the altered data and alert the decision maker before the enemy is able to gain an advantage from the attack. For all the intelligence a computer appears to have, once breached, it usually cannot tell a valid input from an invalid one entered by an attacker. If the system software is unable to determine which data has been altered, it will fall solely to the operator to detect any change.

Vigilance Decrement

While vigilance may be the key to protecting against data manipulation, research has shown that humans are not adept at sustaining attention for long periods of time (Sing and Molloy 1993; Wickens 1999). Mackworth, in 1950, first labeled the inability of an observer to correctly detect infrequently presented signals over time as the "vigilance decrement" (Weiner 1987: 729). Further research by Prarasuraman and Davies confirmed this finding (1984). In general, the longer the observer remains in a vigilance type task the greater the decrease in detection accuracy and speed. While empirical proof exists that a vigilance decrement can occur, the exact causes are widely debated (Weiner 1987).

Parasuraman and Davies argue that the vigilance decrement and level of vigilance are separate phenomenon and may be caused by different processes (1984). In past research, a vigilance decrement could be found in a variety of situational tasks (Weiner 1987; Helton, Dember, Warm, and Mathews 2000). It would seem that regardless of task type, if vigilance is required a decrement could and often does occur. The question then becomes, what was the initial level of vigilance at the beginning of the task? According to the above argument by Parasuraman and Davies, the initial level of vigilance may have been lower in some of the tasks performed. A lower initial level could cause a perceptually greater decrement at least in terms of percentage or critical signals missed. Oppositely, a higher level of initial vigilance may in fact experience the decrement but appear to be less because, at least initially, the subject was able to detect more signals than the person would had a low vigilance level to begin with.

There are a variety of possible factors that contribute to the initial level of vigilance within the computer operator. Such factors could include physical or psychological conditions within the subject, environmental influences, or even varied diurnal constraints that interfere

with the ability or desire to accomplish the given task (Parasuraman and Davies 1984). These problems have been widely studied and remedies are available to reduce their impact on performance (Dittmar and Warm 1993). Even without these conditions, the vigilance decrement can still exist. One possible explanation for the phenomenon is complacency. Having been the subject of a considerable portion of past vigilance studies, the Aviation Safety Reporting System developed their definition of complacency as a "self-satisfaction, which may result in non-vigilance due to an unjustified assumption of satisfactory system state and performance" (Singh and Molloy 1993: 357). Wickens further expands the definition as any situation in which operators are not forced to consider the nature of the decision they are making because it has been automated and their attention has been diverted to other tasks (1999: 6). In an automated environment, there is great temptation to allow the computers to do all of the work, especially if the task is complex and difficult to understand. In these situations, operators can become complacent in their monitoring of the system and consequently reduce their initial levels of vigilance at the onset of the task. In an information warfare data manipulation attack environment, such reductions in vigilance could be devastating. Methods need to be developed to ensure vigilance performance does not decrease over time.

Vigilance/Arousal Relationship

If vigilance is to be the key to detecting data manipulation, the problems of establishing initially high levels, vigilance decrement, and complacency must be eliminated or reduced. One possible way to improve vigilance is through arousal. Paus and Zatore define arousal as "the psychophysiological condition that increases alertness" (1977: 392). In this context, arousal then can be any stimulus that elicits a psychophysiological response in the subject that increases his or

her state of awareness. By arousing subjects, a method may be developed to enhance their performance in a vigilance task.

In 1984, Parasuraman and Davies theorized that temporal changes in performance are directly influenced by a decline in 'perceptual vigilance' or arousal. Their study found that changes in the autonomic and central nervous system activity during the performance of the vigilance tasks showed that the vigilance decrement was accompanied by a decrement in physiological arousal over time (252). Verifying this theory, Sing and Molloy discovered that highly aroused subjects had higher detection rates than did low arousal subjects (1993: 364). Together, these findings suggest a strong correlation between arousal and vigilance within the controlled experiment.

Need for Arousal-Vigilance Research

Parasuraman provided the first empirical evidence that in a controlled setting where subjects were responsible for providing back-up readings for an automated engine status machine, poor monitoring resulted from the over-reliance on automated decision aid (Molloy and Parasuraman 1996). This multitask vs. single task study, however, was criticized for not being realistic due to the artificially high failure rates in the engine status system. In 1996, Parasuraman and Molloy modified the original study to provide a more real-world scenario in which they were able to show that vigilance does decline over a 20-minute period of time with fewer failures present (1996). These findings uphold the theory of the vigilance decrement as well as raise the issue of how to improve vigilance levels in future studies.

Based upon the correlation of vigilance and arousal, further research is required to determine what kind of arousal is most effective in sustaining vigilance through the duration of a

vigilance task. Paus and Zatorre assert that the cognitive processes underlying the detection of target stimuli may fail if the subject's arousal level decreases below a certain point (1997). If true, the stimulus applicable to improving the cognitive function required for error detection may fall within a cognitive style stimulus (i.e., non-physical). Past research has shown that a nonspecific arousal (alerting) process is preferred because of the speeding of reaction time caused by a neutral warning signal or accessory stimulus (Hackley and Valle-Inclan 1999). These two studies seem to indicate that the method of arousal most effective for improving vigilance performance is one that is generic enough to stimulate the cognitive function within the subject. Further research is required to formulate which kind of arousal mechanism would produce the desired results.

In finding arousal's effect on vigilance, Parasuraman and Davies noted that changes in arousal had a greater effect on the level of vigilance than on the reducing or preventing vigilance decrement (1984). Paus and Zatorre further state that the repetitive nature of vigilance tasks requires that adequate levels of arousal be produced (1997). Together, these findings suggest that in addition to nonspecific cognitive arousal stimulus, the arousal method must be directed at instilling a high initial level of vigilance and must be repeated often enough to maintain the level of vigilance required for the task. This specific type of arousal method requires additional research in its development and implementation.

It may be possible to continually arouse subjects to the point where their initial levels of vigilance are restored before the vigilance decrement or complacency phenomenon have an impact. Based on the arousal vigilance research presented above, Figure 2-1 was derived to give a theoretical illustration of how arousal could produce a consistently higher level of vigilance. Continual treatments of arousal stimuli could return initial levels of vigilance to their originally

high state, thereby reducing, but not entirely eliminating, the overall vigilance decrement effect. Line A represents the vigilance level of the subject who has received two arousal stimuli, which returned the subject to his or her initial high level of vigilance. In contrast, line B represents the subject who did not receive any arousal stimuli and continued to experience a vigilance decrement. Over time, the subject receiving arousal stimulus would have an overall higher level of vigilance than the subject who did not receive any stimulus. This graph, therefore, illustrates how arousal may be able to offset the effects of deteriorating vigilance.

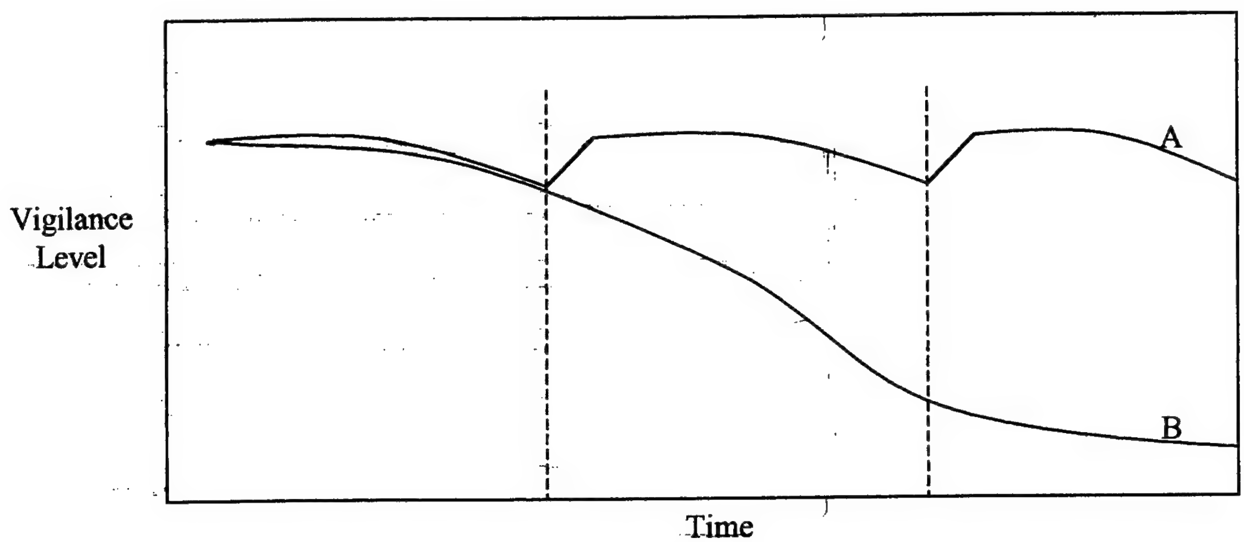


Figure 2-1 Theoretical model of the Effect of Arousal on Vigilance

Arousal Methods

One proven way of arousing subjects is through the use of cues, or hints that something may be changed within the environment under study. Extensive research has been conducted on the application of cues to help subjects improve error detection in a controlled setting (Tipples and Sharma 2000; Blocher et al 1986). Davies and Tune provided results showing that use of reference cues significantly improved performance when compared to the control condition of no reference cues at all (1969). Dittmar reported similar findings when his subjects claimed that

they had used cues as an aid to detection of critical signals (1993). Finally, Bisantz reported in her studies of cue utilization, when cues were present they greatly contributed to judgment performance (2000). In all of these studies cues were given to signify the potential for a critical signal to be present and included a frame of reference of what the signal might look like.

Real world tests have verified that using cues in an operational setting can have an impact on the critical signal detection rate of the test subjects. In 1977, Murrell began a preliminary investigation into the effects of simulated computer cues on a sustained visual monitoring task. His studies showed that subjects with computer assistance (cues) detected more signals than those without computer assistance but also made more false alarms (Parasuraman 1987). Similarly, Yeh, Wickens, and Seagall examined an attention cueing tool for Army threat target recognition. When such a cue was present, subjects "clearly detected the cued targets with greater facility than when cueing was not available" (Wickens et al 1999: 5).

Unfortunately, in an information warfare environment it would often be impossible to cue the computer operator to the exact nature of the data manipulation. As noted earlier, data manipulation attacks are usually attempted in such a way as to hide the manipulation from the operator. Therefore, a more realistic scenario would occur if a network administrator detected an information warfare attack and then issuing non-specific warning to cue the operator for potential data manipulation. Once aroused by the cue, the operator would be more likely to detect any manipulation that had occurred. Such a situation would remain consistent with the findings of Methot and Huitema who demonstrated that artificial injection of signals to generally identify potential targets can be effective in producing high detection levels (1998). While there are many ways of providing cues to the computer operator, this thesis will examine three types: visual, audio, and an audio-visual combination.

Visual Arousal Cues

Visual arousal cues are those that involve providing some type of visual stimuli to the user. Past studies have included flashing lights, pictures, varied color patterns, or textual references (Blocher et al 1986). In 2000, Tipples and Sharma found that rapid flashes of light across potential targets led to improved target-processing reaction times whether the subject intended to ignore the light or not. Their studies concluded that arousal is an important factor in maintaining visual attention or vigilance. The arousal effect of visual cues is created within neurological framework of the human body. Davies and Tune realized that in the case of visual stimuli, increases in the duration and intensity of the stimulus would produce higher detection rates because of "temporal summation at the retina" (1969: 53). Given the previous research and the involuntary nature of the neurological system, any visual arousal stimuli cueing the subject to the potential error may yield excellent benefits for vigilance tasks.

In an information technology based context, visual arousal can be easily conveyed to the user through the use of a graphical user interface. When seeking to defend against data manipulation attacks, visual cues appearing on the computer monitor could be used to alert the operator to potential data errors. In all of the visual arousal studies, the only problem associated with visual stimulus is the increased likelihood of false detections caused by over-arousal (Tipples and Sharma 2000). This phenomenon will be discussed in a later section. The next section, however, explores another sensory type of cue: audio signals.

Audio Arousal Cues

Similar to visual arousal cues, the effectiveness of audio arousal cues is based upon neurological foundations (Mehrabian 1995). These cues, however, are somewhat more limited

in application as they generally take the form of varied sounds or tones. Empirical evidence has shown that the effects of audio signal intensity and vigilance performance are comparable with the results of studies employing visual arousal cues (Davies and Tune 1969). Further, Dwivedi provided evidence that activation of audio arousal improved the detection of "high dominant items" in his study of how audio signals could be used to help single out previously identified items among a host of distracters. (Dwivedi 1992: 266). The "high dominant items" were the target items that needed to be detected amongst other intermixed data. The presence of an audio arousal cue improved the subject's ability to detect the target items (267). These studies suggest a possible positive relationship between audio signals intended to arouse a subject and the subject's subsequent ability to discriminate between critical signals. For vigilance tasks, providing arousing audio signals may provide an initially high level of vigilance.

Like visual arousal cues, audio stimulus could be easily presented to the subject through an information technology platform. Speakers attached to a computer or an audio system installed for the entire room would provide the desired arousal. The only concern with audio arousal would be a training mechanism to orient the subject to what each sound or tone meant. Unlike visual arousal, which can be directed toward the specific problem, audio arousal would need some type of prior conditioning as to what the sounds indicate. If such conditioning were absent, the subject may be aroused by the audio stimuli but would have no direction in which to apply the increased alertness.

Interaction of Auditory and Visual Cues

Based on the results of previous work in visual and audio arousal, it is logical that a positive interaction of the two events could occur. Behavioral and neurological evidence

supports the assumption that an auditory stimulus could have a direct influence on the sensory analyses of the visual stimulus (Hackley and Valle-Inclan 1999). In 1997, Paus and Zatorre discovered that over a period of time, the visual cortex becomes less receptive to repeated stimuli. However, when performing a vigilance task, "repetitive auditory stimulation would gradually attenuate such an activation of the locus coeruleus neurons and in turn restore the spontaneous activity in the visual cortex to the 'normal' level." (1997: 397). In other words, an auditory stimulus could neurologically help prevent any decrease in the effectiveness of the visual arousal method.

Empirical evidence exists to support Paus and Zatorre's theory. In 1976, Lees and Sayers noticed in their studies of the vigilance decrement that little or no decrement occurred when the target signals were accompanied with a loud audiovisual alarm that was almost impossible to ignore (Parasuraman 1987). Such results lead to the possibility that while audio and visual arousal cues alone can improve error detection and reaction times, an interaction of the stimulus may provide the best method for raising the initial levels of vigilance within a subject.

Effectiveness of Arousal Methods

Evidence has shown that arousal can have an effect on the vigilance of subjects (Parasuraman and Davies 1984: 253, Paus and Zatorre 1997: 393). Regardless of method, researchers have recorded improvements in error detection and alertness (Blocher et al 1986: 458). Unfortunately, arousal is not a foolproof tool to improve vigilance. Every advantage afforded by arousing subjects comes with a potential cost that must be mitigated. Over-arousal, habituation, and age considerations all may affect or even limit the benefits of arousal. These problems are discussed below.

Productivity and Over-Arousal. Effective as arousal may be, evidence shows it is possible to over arouse the subject. Hackly and Valle-Inclan determined that increased arousal states lead to improved vigilance or ability to detect subtle changes in the environment, but at the cost of increased errors (1999). These errors generally come in the form of incorrect detections of target signals and can produce a marked decrease in the overall efficiency if the subject spends too much time on detecting, identifying, and processing inaccuracies. Biros found in his 1998 study that arousal is positively related to deception detection but at the cost of increased false detections (1998). Subjects, when highly aroused by stimuli, may begin to make decisions based on less information. In one study, aroused subjects were more sensitive to increasing demands of error detection and chose to perform less verification of targets in order to avoid the cost to performance of missing any key targets (Mosier et al 1999). These studies indicate that arousal must be used in moderation to avoid losses in productivity. However, if productivity is not as great a concern as correctly identifying all data errors, the level of arousal may not matter.

Habituation. A second problem with arousal is the phenomenon of habituation. Repeated exposure to the same stimulus will cause a steady drop in arousal state, known as habituation (Mehrabian 1995). As with any signal, if it is applied often enough, the receptivity of the subject will decrease. Just as a stereo played loudly will not seem as loud over time, a subject exposed to an audio or visual cue may be able to ignore the stimulus altogether. Mehrabrian found in his research that such a decrease in receptivity is usually temporary in nature depending upon the intensity of the stimulus presentation (1995: 6). Parasuraman and Davies encountered similar results in their research (1984). Any researcher or information system developer intent upon improving vigilance performance through arousal methods should

guard against causing a habituation effect within their subjects by either alternating arousal methods or changing some aspect of the cueing sequence.

Age Issue. The final problem associated with arousal and vigilance is the age of the subjects. Mehrabian's 1995 studies showed that "arousable" persons show larger amplitudes of arousal and slower habituation of arousal to baseline or resting levels. In contrast, "unarousable" persons have smaller amplitudes and faster habituation (1995: 5). In other words, subjects who are more susceptible to arousal cues will show higher levels of arousal and will be slower to experience the phenomenon of habituation than subjects who are less susceptible to arousal cues. Mehrabian argues that the more trusting a subject is with the environment they are working in, the more likely they are to block out or ignore the noise around them, thus being less susceptible to arousal cues (1995). In the case of detecting data manipulation errors from an information warfare attack, arousal cues are the intended noise that could be unintentionally blocked out by the computer operator. If the operator has significant trust with the system, he or she may be prone to ignoring any type of warning cues that may be provided. Raab suggests that the only thing required for trust is ignorance of how the technology works and older people tend to be more ignorant of information technology operations than younger people (1998). In a study exploring the use of decision aids in automobiles, it was found that the older subjects implicitly trusted the decision aid due to lack of knowledge of how the system operated and a profound sense of authority the system provided (Fox and Boehm-Davis, no date). Given these results, differences in trust of technology, associated with age, could affect how arousable a subject is.

Waard and Brookuis further examined the issue of age and technology and concluded that while initially older people are reluctant to use or accept technology, once they have experienced the automation they are more likely to develop complete reliance or even

dependency on the system even if they do not understand how the technology works (1998). Similar findings were obtained in a study of automated driving aids and their acceptance among different age groups. This research concluded that middle-aged and older groups were more tolerant and accepting of inaccuracies in technology, while younger age groups had higher expectations and tended to be less tolerant (Fox and Boehm-Davis, no date). These differences in character traits among age groups may lead to differences in how arousal cues affect the subjects. It is possible that younger individuals who are more likely to question the accuracy of computer technology may become more aroused by visual or audio warning cues than older, individuals who are inclined to depend upon technology.

Finally, empirical evidence exists to suggest that the older a person is, the lower their initial vigilance will likely be (Pigeau and Angus 1995). Therefore, an experienced operator who is very trusting of the system in use, not only may have a lower initial level of vigilance due to age but may also be less susceptible to the arousal effects of visual and audio cues. In this case, the computer operator's experience and trust may make him or her very difficult to arouse into high state of vigilance.

Regardless of arousal method, the above research has shown that steps must be taken to limit the effects of overarousal, habituation, and age issues. Once these problems are overcome, it stands to reason that arousal may lead to an improvement in vigilance, while limiting the effects of vigilance decrement. The following section describes a theoretical model of how arousal and vigilance together can lead to improved error detection.

Model Introduction

One of the greatest criticisms of vigilance research has been that the laboratory experiments are not directly applicable to operational environments. Weiner criticized the recent vigilance research efforts by saying that, "Greater efforts must be made by vigilance researchers to develop methodologies for and to seek access to data from real-world systems in order to evaluate questions that cannot be answered in the laboratory." (1987: 734). Given that criticism, any future vigilance research would be remiss if it did not at address its applicability to real world issues. The following theoretical model illustrates how the application of arousal cueing techniques can affect vigilance and error detection within a real-world setting.

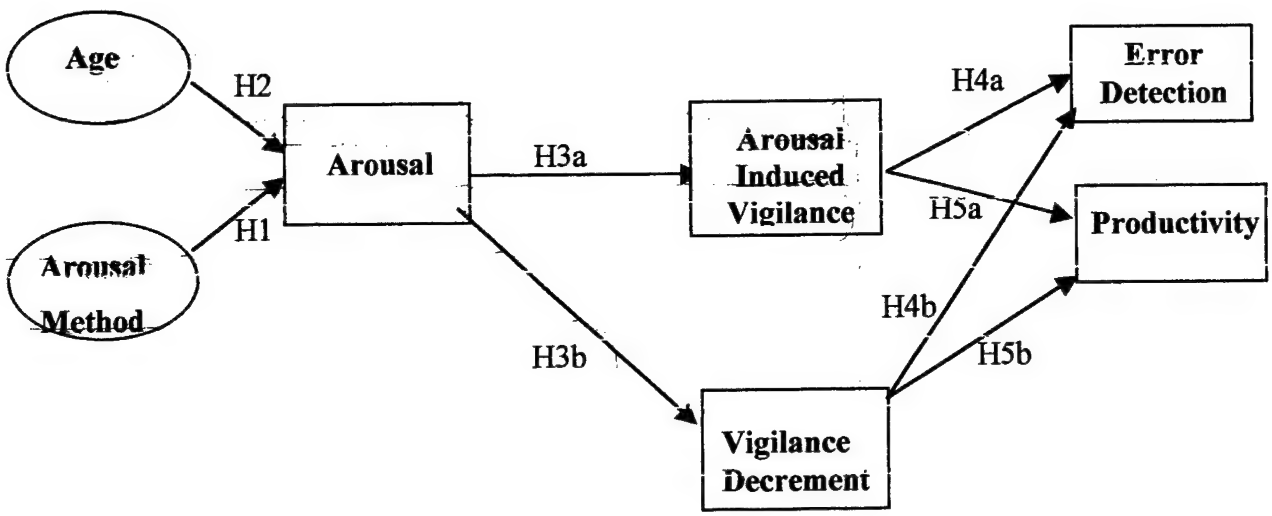


Fig. 2-2 Theoretical model of Arousal-Vigilance Interaction

The basis for this model is wrapped in the research presented above and its development represents the key interactions of arousal, vigilance and the surrounding environment. Following from left to right age and arousal method are the primary components leading to the arousal of

the subject. For this model, the arousal methods are the cue signals (audio, visual, and audio/visual combination) that would alert an individual to the possibility of data errors. Age, in relation to this study, is simply how old the subject is and should be considered its own entity and factor in affecting arousal. Together, these two constructs mitigate the level of arousal within the subject.

The construct, arousal, is the next component of the model. Arousal, as defined by Paus and Zatorre, is the psychophysiological condition that increases alertness (1997). For this model, arousal represents the heightened state of alertness within the subject that is the result of stimuli. It is arousal that is hoped to improve the next construct: vigilance. It is defined as a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment (Mackworth 1957). For this model, vigilance represents the readiness and ability to detect altered data. As with vigilance, arousal is also hoped to reduce the impact of the vigilance decrement phenomenon. Vigilance decrement, by definition, is the decline over time in the rate of correct detection of infrequently presented signals (Parasuraman and Davies 1984). For this model, vigilance decrement refers to the decrease in detections of manipulated data in the periods between arousal stimuli. While still expected to occur, the arousal cueing is hoped to help limit its effects.

The model then demonstrates the relationship vigilance and vigilance decrement have with the final constructs: error detection and productivity. First, error detection is defined as the ability to distinguish between noise and signal (Davies and Tune 1969). For this model, error detection is the ability of the subject to discern incorrect data from the correct data. The inclined arrow leading from vigilance to error detection indicates that higher vigilance states improve error detection. Likewise, the inclined arrow from vigilance decrement to error detection

suggests that as the vigilance decrement is reduced, error detection will improve. The next construct, productivity, is the function of the amount of work accomplished and the efficiency at which it was completed over time. The arrow from vigilance to productivity is declined to reflect the potential for arousal-induced vigilance to cause a decrease in productivity. Finally, vigilance decrement is directly linked to productivity by a inclined arrow to indicate that as vigilance decrement is reduced, the productivity of the subjects increases.

Together these constructs explain how vigilance can be theoretically improved by arousal. Following the model from left to right, illustrates the dynamic affect of each construct on the next. The following section will explore the hypotheses alluded to by the model and discuss their implications.

Hypothesis Generation

In general, the model illustrates the sequence of events required for arousal to affect vigilance and the potential outcomes of such an interaction. The following hypothesis drives that theoretical sequence of events.

The first part of the model deals with the component that affects the arousal mechanism within the subjects. Based on past research, the application of visual and audio stimulus to the subjects will increase the individual arousal levels within the subject. In a study conducted by Hackly and Valle-Inclan, their results showed that the self reported levels of arousal were significantly higher for those that received an arousal signal than those that did not (1999). It is this increase in arousal that will begin the process of improving vigilance performance. However, while it is believed that visual, audio, and combination stimuli will improve arousal, each stimuli type affects the psycho-physiological systems of the subject differently (1999).

Therefore, first three hypotheses are directed at exploring each stimuli type individually and are as follows:

H1a: The arousal method of audio clue signals will have a positive affect on arousal.

H1b: The arousal method of visual clue signals will have a positive affect on arousal.

H1c: The arousal method of audio and visual combination clue signals will have a positive affect on arousal.

Unfortunately, arousal may not be effective for everyone. In addition to the findings of increased arousal after stimulus application, other studies have presented evidence that age levels can affect how aroused a subject gets (Dittmar and Warm 1993; Pigeau and Angus 1995). According to these studies, the greater age a subject has will tend to lead to a decrease in "arousability". Therefore, the arousal cue signals will be less likely to have an effect upon older decision makers, thus leading to the second hypothesis:

H2: Older ages will limit the arousal effects of computer generated cue signals

There is little doubt, based upon empirical evidence, that an aroused subject will be more vigilant (Mosier et al 1994). However, only theory provides that arousal typically will affect initial vigilance levels and do little to help prevent the vigilance decrement (Parasuraman and Davies 1984). The model indicates that a relationship between arousal and vigilance will exist. Additionally, regardless of how much arousal is applied to a subject, prior research cautions that only the initial level of vigilance will be impacted. These results indicate that despite being aroused, the subjects are still likely to demonstrate a slight vigilance decrement over time. However, when compared to subjects who are not aroused at all, the decrement is less because the repeated application of arousal methods has restored the initial vigilance levels and minimized the total decrement experienced. This relationship is what will possibly allow a

continued high state of vigilance and a reduction in vigilance decrement. Therefore the third hypothesis is:

H3a: Increased arousal has a positive association with the level of vigilance.

H3b: Rates of vigilance decrement will be lower with aroused subjects than with non-aroused subjects.

Vigilance was defined above as an ability of a subject to notice subtle changes within the environment. If subjects are either initially vigilant or made so through arousal, they should be able to successfully detect errors when present due to their ability to detect simple changes within the environment they are working in. Additionally, if the subject is not experiencing a significant vigilance decrement, he or she are more likely to remain able to detect errors for extended periods of time. The relationship between higher states of vigilance, reduced vigilance decrement, and error detection leads to the fourth hypothesis:

H4a: Increased states of vigilance have a positive association with successful error detection.

H4b: Improved vigilance decrement has a positive association with successful error detection.

While arousal may be an effective way to increase vigilance, it is often not without cost. The productivity of subjects, in terms of time spent on incorrect detection, may be inversely related to the level of arousal-induced vigilance. In other words, as arousal increases within the subject, a decrease in productivity may simultaneously occur. Improved vigilance decrement, however, may mitigate the effects of decreased productivity by allowing the subjects to retain their ability to detect small changes in the environment around them over time. This relationship is the basis of hypothesis five:

H5a: Increased states of arousal-induced vigilance have a negative association with productivity.

H5b: Vigilance decrement has a positive association with productivity.

The hypotheses generated above describe a theoretical relationship between the constructs. Chapter three will develop an experiment to examine the validity of these hypotheses. Only through application can it be known if they are accurate.

Summary

The need to improve a subject's vigilance in critical tasks remains clear. Arousal cueing may provide the necessary means for increasing at least the initial levels of vigilance. If issues of over arousal, habituation, and age can be brought under control, an effective method for preventing data manipulation errors as well as those of other detection tasks may be developed. Past research suggests a correlation between arousal, vigilance and vigilance decrement, therefore this study seeks to further refine the field as well as provide real-world system developers key tools they can use to prevent future mistakes caused by a lack of vigilance, particularly in the case of data manipulation attacks.

CHAPTER 3: METHODOLOGY

Overview

The purpose of this chapter is to describe the methods and procedures used in conducting research on the effects of arousal on vigilance. It includes a description of population, sample and measurement instruments used in the study. Additionally, data collection instruments and proposed analysis methods will be discussed.

Objective

This study was conducted to provide research on the effects of vigilance on error detection within an information warfare environment. As stated earlier, vigilance may only be effective for a limited time. Therefore, this experiment design incorporated various arousal methods in an attempt to improve vigilance within the context of a data manipulation attack.

Additionally, in order to obtain greater value from the outcome of this research, attempts were made to avoid known criticisms of previous vigilance experiments. In 1984 Mackie concluded "90% of the vigilance studies were conducted in a way that that would make it doubtful that the findings could generalize to civil or military systems" (Adams 1987: 738). The shortcomings tended to include a severe lack of realism that may have been prevented by the use of simulators representing a multitask environment (Gluckman and Warm 1993). This research, therefore focused upon providing a reality-based vigilance task within a multitask framework with a simulation as the primary means of data collection.

Subjects

Before creating the vigilance experiment and selecting the data collection instrument, the issues of sample population and sample size became a concern. For this study, the sample population consisted entirely of Air Force officers. Officers are the final decision makers in most military scenarios and therefore were appropriate choices for a study designed to improve vigilance and error detection. The officers were divided into two groups based upon age. Air War College students, senior officers from Lt. Col to Colonel made up the older aged group while AFIT students and the Aerospace Basic Course cadre, junior officers from lieutenant to captain, filled the younger aged group. Subjects were enticed to participate in the study by offering a $25 gift certificate to the officers club for the subject who had the highest overall score during the simulation.

A power analysis was conducted to determine the number of subjects the study required. A power analysis was completed and a total sample size of 48 was deemed appropriate. This sample size provided, at a significance of .05, a power of .997. The results of the power analysis are located in Appendix A.

Instruments

In searching for a data collection tool, three requirements existed: realism, modifiability, and simulation based. In coordination with the Aptima Corporation, the Distributed Dynamic Decision-making system (DDD) was selected for use in this study. DDD is a simulation-based program with a high degree of modifiability, in which subjects can be exposed to a variety of military-related situations. The DDD instrument is self-contained and can be staged on nearly

any computer platform. While Aptima produced the shell of the program, each individual scenario had to be scripted and coded into the system.

Using DDD, each subject was assigned the role of an air defense commander deployed to a hostile foreign country (Appendix B). Reinforcing the realism of the study, a current potential problem area of the world was selected for the scenario. Each subject was tasked to identify aircraft entering his or her assigned airspace based upon information provided by two distinct sources: radar and a decision support aid. The subject, after identifying the aircraft, had to decide whether to allow the aircraft to enter the airspace or to shoot it down. Figure 3-1 provides a snapshot of the screen displayed encountered by the subjects.

Given the difficulty of encountering a new program, an extensive training session was built into this experiment. This training served two purposes. First, it educated the subjects on the use and functionality of the DDD system, while its secondary purpose was to alert the subjects to the distinct nature of the two sources of information. For this experiment it was necessary to create separate sources of information from which the subject could discern conflicts in data, or the errors caused by a data manipulation attack. This was accomplished by providing the subject their primary decision making data through a decision support system which combined data from multiple radar sources over a network vulnerable to information warfare attack, while allowing a secondary reference source of data directly from a specific radar site immune to attack. Appendix C contains the training slides used for this experiment.

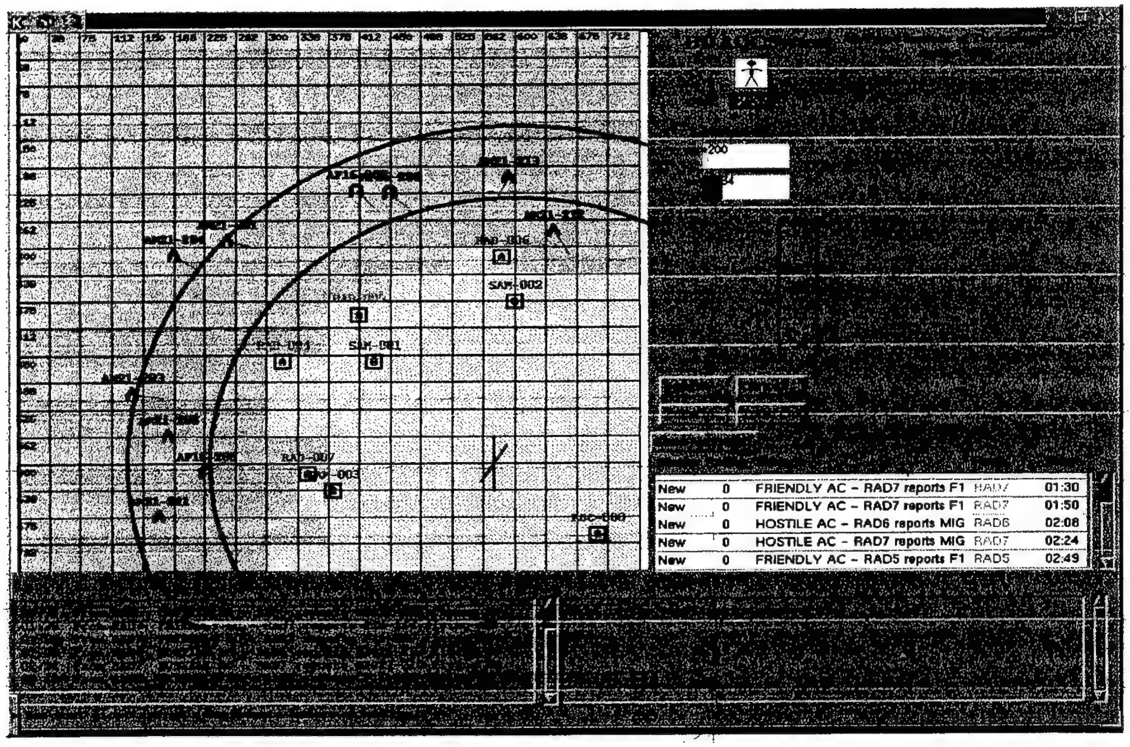


Figure 3-1 Sample Screen-Shot of the DDD System

A second data collection tool used in this study was a questionnaire. The questionnaire solicited demographic data as well as information on how well the subject received and understood the training on how to use the DDD system. More importantly the questionnaire also provided self-reported arousal levels for each subject. Using a modified 7-point Lickert scale, employed by Hackley and Valle-Inclan in 1999, the subjects were provided a definition of arousal and then asked to rate how aroused they felt during the simulation (326). The four-part questionnaire is located in Appendix D.

Experiment Design

Viglance tasks, as stated earlier, are those that require sustained attention to detect subtle changes within the environment. Extensive studies have been conducted using vigilance tasks and a volume of information exists on their methods and design. Based on these studies, Jerrison

(1970) and Warm (1984) outlined a framework for building a vigilance task (Percival and Noonan 1987). The four required elements are displayed in Table 3-1. The design of this experiment was guided by the four elements.

1	The task is prolonged and continuous.
2	The signals to be detected are highly discriminable to an alerted observer.
3	The signals are infrequent and aperiodic.
4	The monitor's response has no effect on signal rate.

Table 3-1: Jerrison and Warm's Framework for Vigilance Research

<u>Prolonged and Continuous</u>. The first element contains two parts, prolonged and continuous. Of great concern in designing the experiment was the length of time in which to conduct it. Teichner, in 1974, noted that the vigilance decrement was typically complete within 35 minutes after the initiation of the vigil (Hollenbeck et al 1995). Other vigilance researchers have considered a 20-minute task to be sufficient for producing a vigilance decrement effect (Molloy and Parasuraman 1996). Given these findings and the constrained time to complete this study a 20-minute vigilance simulation for each subject was deemed to be within the framework outlined by Jerrison and Warm.

Regarding the continuous nature required by Jerrison and Warm, "it has been suggested that a rate of at least 20 – 24 events/minute are needed to observe a vigilance decrement" (Pigeau and Angus 1995: 631). Using the DDD simulator, the number of possible events per minute was at least 25, depending upon the speed of the subject. These events included the subject's actions of verifying tracks, reporting discrepancies, and destroying enemy aircraft. Based on the prior research, this experiment satisfied the continuity requirement.

<u>The signals to be detected are highly discriminable to an alerted observer</u>. The second requirement for a vigilance study is to have highly discriminable signals for the subject to detect. As mentioned earlier, each subject was provided two distinct data sources. The first, and primary, source of data was the display screen, which graphically represented the fused data of multiple radar sites. On this screen, aircraft type and location were presented through the use of icons to the subject for action. The secondary source of information appeared as messages from individual radar sites. These messages also included aircraft type and location. The signal the subject searched for was a discrepancy between the two sources of data. The subjects were trained that the graphical display operating over a local area network may have been vulnerable to information warfare attacks, while the messages from radar sites are transmitted securely to the subject. The subjects were able to simultaneously view the information provided by both sources and thereby discern any deviations in the data sources, thus satisfying the second element of the vigilance framework.

<u>The signals are infrequent and aperiodic</u>. Included within the simulations events were a total of 10 erroneous targets out of 55 possible. Past research on vigilance and error detection included error rates ranging from 1 possible error for the entire study to an error rate of 1/3 of the total possible targets (Biros 1998; Molloy and Parasuraman 1996). Given the study attempted to recreate an information warfare environment in which data manipulation occurred, the error rate of 18% was within reason. Additionally, the errors needed to be presented to the subjects in an aperiodic fashion to prevent the subjects from discerning a pattern within the experiment. This experiment was divided into six sections, transparent to the subject, in which the number of errors are distributed to each section as follows 1, 2, 2, 3, 2. This distribution helped prevent the subjects from being aroused to a specific pattern of errors thereby reducing the validity of the

experiment. The infrequent and aperiodic design of this test satisfied the third element of a vigilance test.

The monitor's response has no effect on signal rate. Finally, in order to build a good vigilance experiment, the responses of the monitor must have no impact on signal rate. Using the DDD system, the errors were pre-programmed to occur at specific times and intervals and could not be changed or modified by user actions. However, the time at which the subject discovered the errors depended upon the speed and efficiency of the subject. Therefore, each error was given a time window, corresponding to the sections mentioned above, in which it would appear and provide and opportunity for detection before it was no longer available to the subject and counted as a missed detection. In a multitask, data manipulation setting it was likely the error may occur minutes, hours, or even days before the altered information is even presented to the user. Regardless of detection time, the detection event will not affect signal rate at all, thus satisfying the final element of a vigilance experiment.

Design Considerations

While the experiment design was based on Jerrison and Warm's framework, additional features were added to facilitate data collection and analysis. In order to objectively determine when the subject noticed a discrepancy in the data, they were required to click on a discrepancy button with the mouse. At the same time, the subjects were forced to rate how confident they were in the decisions they made. The confidence, based on a scale of one to five, allows additional information to be gained about what the subjects really intended or discerned about the data they are examining (Balakrishnan 1998). The combination of a yes/no discrepancy

button and the confidence level rating helped ensure the subject really meant to express there was an error instead of making a mistake or simply not understanding the task.

Finally, included in the design of the experiment was an incentive to perform well. A weighted scoring incentive was provided to encourage a realistic environment of cost and rewards. The scoring table used by the subjects is located in the training slides in Appendix C. Prior vigilance research has shown that subjects tend to be aggressive when either costs are low or values are high but conservative when the converse is true (See et al 1997: 16). The scoring system used was designed to give greater rewards for correct decisions and assess higher costs for incorrect decisions as their confidence rating increased. This system forced the subjects to consider the impact of the choices they make in the simulation, similar to the costs and rewards associated with an actual military situation. Additionally, the weighted scores helped avoid the over aggressive/conservative problem noticed by See and others in 1997.

Experiment Manipulations

As mentioned earlier, arousal is one potential means for improving vigilance performance. Having established a vigilance experiment, four manipulations were added to explore the effects of arousal on vigilance performance. For this study, the subjects were evenly divided into two groups based upon age. Group 1 was comprised of subjects age 35 and older with an average of 42.65 years, while Group 2 consisted of officers age 34 and younger with an average age of 27.8 years. Within each group, each subject was randomly assigned to one of four subgroups. Subgoup 1 served as the control group and received no arousal stimulus. Subgroup 2 received an arousal stimulus of an audio warning cue, while subgroup 3 received a

visual warning cue. Subgroup 4 received a combination visual and audio cue. The following 2 x 4 matrix illustrates the division of groups and the application of arousal methods.

	No Cue	Audio	Visual	Visual and Audio
Older Group (1)	1-1	1-2	1-3	1-4
Younger Group (2)	2-1	2-2	2-3	2-4

Figure 3-2 2x4 Experimental Design Matrix

The visual arousal cue included a pop-up window that warned the subject of potential information warfare attacks. The audio arousal cue was a three second tone emanating from the computer. The combination signal includes both elements of the visual and audio arousal cues. During the training phase of the experiment, the subjects were acquainted with the cues in order to ensure there was no misconception of what each meant. Finally, the computers were programmed to not make any sounds or provide any kind of pop-up windows, which could be misconstrued by the subjects as false warnings.

Pilot Study

Before conducting the actual experiment, a pilot study was conducted to validate the design of the experiment and its measures. For the pilot study, 10 company and field grade Air Force officers were the subjects. Upon analysis of the data provided by the shortened study, effective measures were determined for describing the hypotheses listed in Chapter 2.

Additionally, the pilot subjects addressed ergonomic considerations and minor display changes were made to the program. Overall the pilot study data suggested the experiment design and data collection measures were sound.

Hypothesis Measures

The primary source of data collection resides within the DDD system. Statistics on subject performance such as errors detected, time of detection, incorrect detections, and confidence levels are recorded by the system. Additionally, a questionnaire was used to determine overall arousal levels within each subject. These two sources of data provide the basis of the study's hypothesis measures. The following table represents the measures for each hypothesis.

Hypothesis	Measure(s)
H1(a,b,c): The stimuli of audio and visual clue signals will have a positive affect on arousal.	Arousal level from questionnaire compared to the type of stimuli presented
H2: Older age will limit the arousal effects of computer generated cue signals.	Self reported arousal levels compared between groups and subgroups based upon age and arousal method
H3a: Increased arousal positively affects the level of vigilance.	Correct detections per time period after arousal cues applied
H3b: Rates of vigilance decrement will be lower with aroused subjects than with non-aroused subjects.	Vigilance curves based on correct detections per time period compared to self reported arousal levels
H4a: Increased states of arousal –induced vigilance positively affect successful error detection.	The number of correct detections compared to vigilance levels
H4b: Improved vigilance decrement has a positive association with successful error detection.	The number of correct detections compared to vigilance curves over time
H5a: Increased states of arousal-induced vigilance are at the expense of decreased productivity.	Incorrect detections, time taken to detect, and number of times detected compared against vigilance levels
H5b: Improved vigilance decrement has a positive association with productivity.	Productivity levels per time period compared to vigilance curves

Table 3-2: Hypothesis Measures

Each of the above measures is based upon the actions of the subject. Also collected by the DDD system are confidence levels associated with each subject's actions. While not directly related to the hypothesis of this paper, the confidence levels can be used as measures of the subject's intentions. Further explanation of the measures is included in Chapter 4.

Data Analysis

Once the measures were developed and the data compiled, statistical analysis was conducted for each measure. Linear regression was the primary statistical tool used in the data analysis. The regression allowed an easy determination of the factors that had the greatest influence on next construct in the model. Additionally, t-test tools were used for determining the significance of data comparisons between groups 1 and 2 and ANOVAs were used to find the differences between models (Biros 1998; Vankatesh, Morris, and Ackerman 19xx). Finally, the vigilance curves were statistically analyzed through regression methods developed by Methot and Huitema in 1998 (106).

Summary

The experiment design, manipulations, data collection tools, and hypothesis measures developed in this chapter have been created to test the effects of arousal on vigilance and error detection. Every attempt was made to provide a realistic experiment with direct applicability to information warfare, particularly data manipulation, defense procedures. Chapter 4 will discuss the outcome of this design and determine which hypotheses were supported.

CHAPTER 4: RESULTS AND ANALYSIS

Introduction

This chapter presents a statistical analysis of the data collected from the experiment designed in the previous chapter. It will examine the effects of stimuli type and age on arousal levels and the subsequent impact on vigilance and vigilance decrement. Further analysis will explore how changes in vigilance affect correct detection and productivity. These findings will be related to the hypotheses generated in chapter two and discussion of hypothesis validity will be included.

Experiment Data

The DDD system provided data on every action the subjects took throughout the experiment and questionnaires were used to obtain other data on each subject. The first step in analyzing the data provided by these two sources was to identify and codify the hypothesis measures from the raw data. Key measures used in this study were age (A), arousal level (AL), vigilance (V), correct detection (CD), productivity (P), and vigilance decrement (VD). Age and arousal level values were taken directly from the questions answered by each subject. Vigilance, correct detection, productivity, and vigilance decrement were determined based upon standards established in prior vigilance experiments in which detections over time served as the baseline for development of each measure (Parasuraman and Davies 1984; Bisantz 2000; See et al 1997). Together, these seven variables represent each portion of the model developed in chapter 2 and serve as the basis for the data analysis in the following sections. A full descriptive analysis of each variable and any applicable interaction is located in Appendix E. Having identified and separated the key measures, the analysis could begin.

Analysis Tools

In analyzing the data, the primary tool used was regression. The theoretical model used in this study followed a steady progression of events in which the previous event influenced the subsequent events. Therefore, a regression analysis provided an easy method for determining which factors actually influenced the next variable and to what degree the influence was exerted. However, since the subjects had been split into two groups based upon age levels, a comparison between the groups was also required. Using an analysis technique reported by Cohen (1983) and used by Venkatesh, Morris and Ackerman, a t-test of the beta values from the regression model was conducted to see if there were any significant differences between groups (2000). Additionally, an Analysis of Variance was used to see if there were any differences between the models. The following sections explore the results of the data analysis in relation to each hypothesis.

Analysis Results

<u>Effects of Stimuli Types and Age on Arousal.</u> In analyzing the data, the first two hypotheses (H1a,b,c and H2) were examined together. A regression model was built for each group (old vs. young) with all of the factors that may have contributed to the changes in arousal states. The mean arousal for group 1 was 4.45, while group 2 had a mean arousal of 5.27 on a scale of 1 to 7. It had been expected that stimuli (S) would have a positive affect on arousal but that it would be limited by the age of the subjects. For this model, stimuli was reduced to the individual arousal methods employed in order to determine which of the arousal methods had the greatest impact. Additionally, the interaction of age and stimuli was also explored. The resulting regression model was as follows:

$$AL = A + S\ (\text{audio, visual, audio/visual}) + SA$$

For group 1, the model yielded an R^2 of .149 with visual and audio-visual combination having a moderately significant positive affect on arousal and audio stimuli, age, and the age-stimuli interaction having no significant effect on arousal levels. Group 2, however, had an R^2 of .472, with visual, audio-visual combination, age and the stimuli-age interaction having a moderate to significant effect on arousal level. Between the two groups, an ANOVA revealed a significant difference (.000) between group 1 and group 2, while a t-test revealed a significant difference between the individual betas for age and stimuli-age interaction. Table 4-1 summarizes the results of the regression, ANOVA, and t-test analysis of betas.

	Group 1			Group 2			Significance of Difference	
	R^2	Beta	p	R^2	Beta	P	Model	Beta
	0.149			0.472			0.000	
Audio		0.243	0.255		0.450	0.189		0.252
Visual		0.853	0.078		1.091	0.003		0.176
AV Comb		1.043	0.047		0.991	0.012		0.390
Age		0.166	0.616		0.851	0.078		0.032
Sti-Age Int		.982	0.325		2.288	0.041		0.008

Table 4-1: Factors Affecting Arousal

H1a: The arousal method of audio clue signals will have a positive affect on arousal.
H1b: The arousal method of visual clue signals will have a positive affect on arousal.
H1c: The arousal method of audio and visual combination clue signals will have a positive affect on arousal.

The results of the data analysis indicate no support for H1a in either group for audio stimuli influence on arousal. In other words, the subjects did not have their arousal levels significantly increased by the audio arousal cues. H1b and H1c did receive significant support from both groups. For group 1, visual (.078) and the audio-visual combination (.047) were

moderately significant in positively affecting the subject's arousal level. For group 2 the results were the same, but with a strong significance for both visual (.003) and audio-visual combination (.012). The regression models for both groups indicate that the subgroups, which received visual and audio-visual combination arousal methods, had the greatest influence on arousal levels. The differences between the group's betas were not significant for any of the stimuli types.

H2: Older ages will limit the arousal effects of computer generated cue signals

For H2, however, the results are mixed. Group 1 had no significant relationship between age or sti-age interaction and arousal. In contrast, for group 2, age (.032) and sti-age interaction (.008) had a strong significant effect on arousal. The implications for group 2, include the possibility that while age had a negative association with arousal, the stimuli type and sti-age interaction influence on arousal were great enough to offset any negative impacts of age. The difference between the group's betas, determined by the t-test, was significant at .032 for age and .008 for the sti-age interaction, thereby indicating that the effects of age and the sti-age interaction varied between groups. Finally, group 1 was most impacted by the combination of audio and visual stimuli, while group 2 was influenced by both visual and the combination stimuli, as indicated by the betas for the different arousal methods.

Effects of Arousal on Vigilance. Vigilance, for this study, is the ability to detect errors in the data over time. Figure 4-1 illustrates the average vigilance curve for each subgroup for this experiment. These curves indicate the subject's ability to detect errors over time. They also demonstrate vigilance decrement. Vigilance decrement, for this study, is the rate of decrease in vigilance. For figure 4-1, a more sharply declined slope indicates a higher vigilance decrement, while a lower vigilance decrement is indicated by a shallow or slightly decreasing slope. This figure will be referred to for the following data analysis sections.

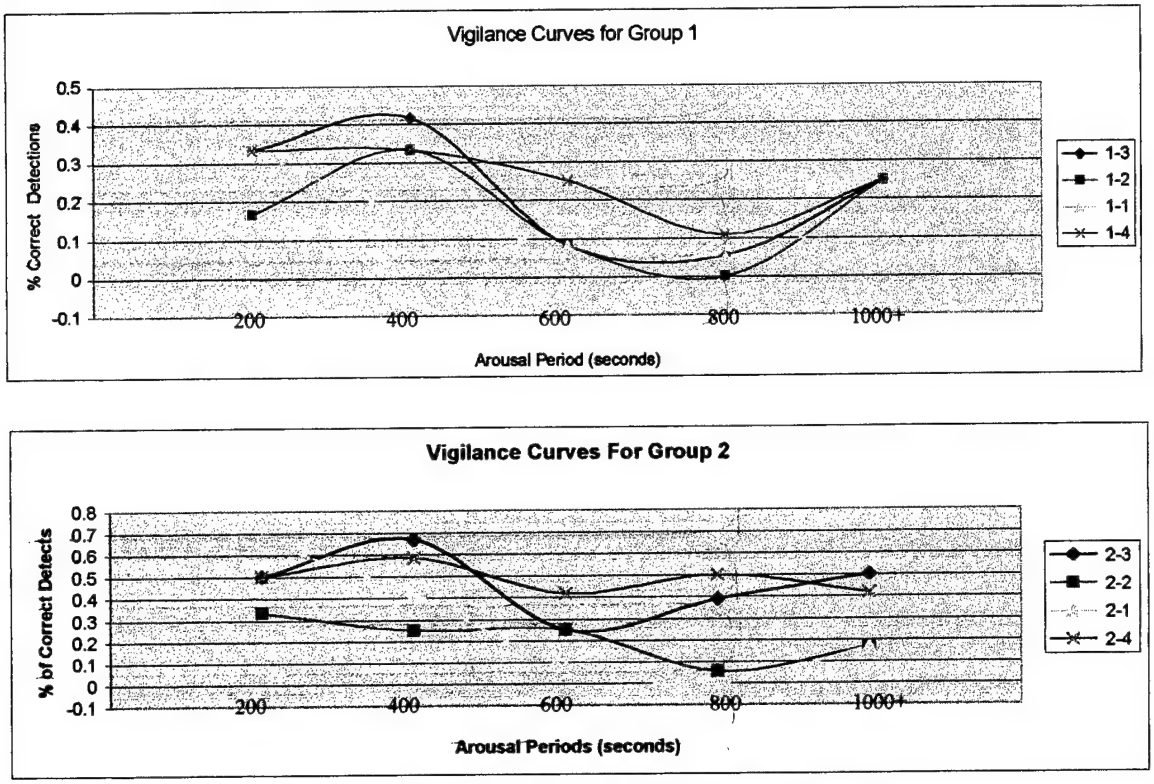


Figure 4-1: Vigilance Curves for Groups 1 and 2

It was expected that once aroused, a subject would possess a higher state of vigilance than if not aroused. Therefore, the second regression analysis centered on finding the factors that influenced the level of vigilance within a subject. For this and future models the arousal methods are grouped together as a single stimuli factor. The regression equation included:

$$V = S + A + AL + SA$$

An interaction component between stimuli and age (SA) was also initially considered. The above equation provided an R^2 of .119 for group 1 and a somewhat higher value of .271 for group 2. Additionally, an ANOVA established a significant difference between the models of .000 and the t-test determined a significant difference between the beta for age (.051) and sti-age interaction (.012). Table 4-2 summarizes the results of the regression analysis, ANOVA, and t-test for H3a.

	Group 1			Group 2			Significance of Difference	
	R^2	Beta	P	R^2	Beta	p	Model	Beta
	0.119			0.271			0.000	
Stimuli		0.256	0.774		0.761	0.068		0.406
Age		0.069	0.829		-0.819	0.156		0.051
Sti-Age Int		0.073	0.940		1.720	0.198		0.012
Arousal		0.005	0.964		-0.029	0.793		0.113

Table 4-2 Factors Affecting Vigilance

H3a: Increased arousal has a positive association with the level of vigilance.

For H3a, there was no indication that arousal was associated with vigilance. However, it should be noted that while arousal itself did not have significant impact, stimulus type did have a moderate positive association with vigilance at a significance of .068 for group 2. Similar to H2, the high positive beta for the stimuli factor suggests that at least for group 2, the subjects who received the visual and audio-visual combination arousal methods did experience a positive influence on their vigilance levels. While this moderate influence occurred for group 2, the difference between group 2 and group 1 was insignificant, thereby demonstrating how limited the influence actually was.

Again, in Figure 4-1 an ANOVA of the curves indicated a significant difference between the subjects receiving the audio-visual stimuli and those who received no stimuli for both group 1 and group 2. Additionally, group 2 also showed a significant difference between subjects receiving visual stimuli and those who received no stimuli. These results will be discussed further in the following section.

<u>Effects of Arousal on Vigilance Decrement.</u> The next analysis conducted was on how arousal influenced vigilance decrement. It was expected that arousal would cause a continuously higher state of vigilance thereby reducing the vigilance decrement phenomenon. However, H3a

indicated that arousal had not affected vigilance. Therefore, the regression model included arousal, stimuli, age, and the sti-age interaction in order to determine other possible influences on vigilance decrement. The final model was as follows:

$$VD = S + A + SA + AL$$

This model provided an R^2 of .183 for group 1 and an R^2 of .142 for group 2. The ANOVA showed only a modest significant difference (.089) between the models, while the t-test of beta's proved significant for stimuli (.032), age (.004), and the sti-age interaction (.001). Table 4-5 shows the results of the regression analysis.

	Group 1			Group 2			Significance of Difference	
	R^2	Beta	P	R^2	Beta	P	Model	Beta
	0.183			0.142			0.089	
Stimuli		0.775	0.367		1.431	0.182		0.032
Age		0.152	0.624		-1.188	0.058		0.004
Sti-Age Int		0.408	0.662		2.526	0.082		0.001
Arousal		0.192	0.040		-0.131	0.280		0.337

Table 4-3: Factors affecting Vigilance Decrement

H3b: Rates of vigilance decrement will be lower with aroused subjects than with non-aroused subjects.

H3b suggested that the rate of vigilance decrement would be lower with aroused subjects than with non-aroused subjects. Group 1 found that arousal had a strong influence (.040) while group 2 experienced no significant positive affect on vigilance decrement by arousal. Instead, vigilance decrement for group 2 was moderately impacted by age (.058) and the sti-age interaction (.082). These results indicate that for the older group arousal did influence the vigilance decrement while for the younger group other factors such as age and its interaction with stimuli had more of an affect. As a result, only group 1 provides support for H3b.

In figure 4-1, the vigilance decrement can be seen as the declining slope of the vigilance curve over time. For group 1 and group 2, the subjects who received the audio-visual combination stimuli had the lowest rates of vigilance decrement as indicated by the shallow sloping curve. An ANOVA of the different curves for group 1 showed a significant difference (.011) between 1-4 (audio-visual) and the control group 1-1 (no stimuli). All other subgroups for group 1 were deemed to have no significant difference compared to the control group. Additionally, for group 2, the ANOVA found subgroup 2-3 (visual) and 2-4 (audio-visual) to be significantly different than the control group (no stimuli) at a level of .002 and .005 respectively.

Effects of Arousal induced Vigilance and Vigilance Decrement on Correct Detects. The relationship between arousal, vigilance, vigilance decrement and correct detection was expected to be positive. In order to determine how the relationship existed the following regression model was developed:

$$CD = S + A + SA + AL + V + AV + VD$$

This model contains the factors of stimuli, age, sti-age interaction, arousal, and vigilance, arousal-vigilance interaction, and vigilance decrement. The stimulus, age, and sti-age interaction factors were included due to the weak association of arousal to vigilance demonstrated above. It seemed possible that in addition to arousal, other factors such as an arousal-vigilance (AV) interaction could have also influenced the number of correct detects. The model produced an R^2 of .144 for group 1 and a .148 for group 2. An ANOVA showed a modest difference between the group 1 and group 2 of .073 and the t-test only showed a significant difference between the factors age (.074), sti-age interaction (.003), arousal (.056), and vigilance (.078).

	Group 1			Group 2			Significance of Difference	
	R^2	Beta	P	R^2	Beta	P	Model	Beta
	0.144			0.148			0.073	
Stimuli		0.231	0.800		0.227	0.088		0.110
Age		-0.239	0.463		0.075	0.449		0.074
Sti-Age Int		0.306	0.756		-0.342	0.211		0.003
Arousal		-0.550	0.040		0.126	0.585		0.056
Vigilance		1.155	0.014		0.354	0.525		0.078
Vigilance Dec		0.276	0.208		0.359	0.064		0.428
Arous-Vig Int		1.125	0.013		1.136	0.076		0.387

Table 4-4: Factors Affecting Correct Detection

H4a: Increased states of arousal induced vigilance have a positive association with ~~successful error detection.~~

H4b: Improved vigilance decrement has a positive association with successful error detection.

For H4a, significant support was found to indicate that vigilance did have a positive association with error detection for group 1. Vigilance (.014), arousal (.040), and the arousal-vigilance interaction (.013) all indicate a moderate to strong significance for influencing error detection for group 1. In contrast, group 2 only recorded a moderate significance (.076) for the arousal-vigilance interaction influence on error detection. The ANOVA registered a moderate difference (.073) between the models and the t-test indicated no significant difference between the any of the factors for each group. These results suggest that for group 1, higher levels of vigilance, as indicated by higher Beta values, do positively affect the error detection ability of the subjects. Therefore, H4a can only be partially supported by the findings for group 1.

Referring back to figure 4-1, the vigilance curves essentially show the correct detection of errors over time. As noted above, the vigilance levels, especially those of the subjects who received the audio-visual combination stimuli (1-4 and 2-4), experienced significantly less vigilance decrement, thereby allowing better error detection over time. In this study, subgroups

1-4, 2-3, and 2-4 represent visual and audio-visual combination stimuli. Their graph and t-test analysis indicate that they had the best influence on error detection.

For H4b, significant support was found to suggest that improved rates of vigilance decrement would influence error detection for group 2. The regression model seems to indicate that at least at a moderate level of significance (.068), error detection can be improved by a reduction in the rate of vigilance decrement. Group 1, however, did not see any significant influence on error detection from vigilance decrement. Therefore, H4b is only partially supported.

Effects of Arousal induced Vigilance and Vigilance Decrement on Productivity. While higher states of vigilance were expected to improve error detection, the opposite was expected to be true for productivity. Improved vigilance decrement was also anticipated to aid in error detection, but without causing the undesired effect of reducing productivity. The effects of vigilance and vigilance decrement on productivity are reflected in the following model:

$$P = S + A + SA + AL + V + VD + AV$$

Similar to H4(a,b) the factors of stimuli, age, sti-age interaction, arousal, arousal-vigilance interaction were included to help explain productivity. For group 1, the model produced an R^2 of .094, while for group 2 it gave and R^2 of .085. The ANOVA showed a moderate difference between models (.063) and the t-test only showed a significant difference between the sti-age interaction and vigilance factors. Table 4-4 shows the results of the regression and t-test analysis.

	Group 1			Group 2			Significance of Difference	
	R^2	Beta	p	R^2	Beta	p	Model	Beta
	0.094			0.085			0.063	
Stimuli		0.219	0.815		0.077	0.572		0.687
Age		0.209	0.533		-0.063	0.537		0.396
Sti-Age Int		-0.353	0.727		0.188	0.761		0.056
Arousal		0.449	0.102		0.271	0.259		0.433
Vigilance Dec		0.153	0.495		0.003	0.989		0.375
Vigilance		-0.340	0.475		1.081	0.063		0.079
Arous-Vig Int		-0.923	0.047		-1.353	0.042		0.353

Table 4-4: Factors Affecting Productivity

H5a: Increased states of arousal-induced vigilance have a negative association with productivity.
H5b: Vigilance decrement has a positive association with productivity.

The regression model indicates that for group 1, vigilance had significant (.020) negative influence upon productivity. In contrast, however, for group 2, vigilance had a moderately significant (.074) positive influence upon productivity. The arousal-vigilance interaction was found to be significant for both group 1 and group 2 at a significance level of .047 and .042 repesctively. These results suggest that for the older group, the more vigilant a subject became the more likely they were to develop unproductive behaviors such as incorrectly identifying errors that did not exist or simply spending too much time analyzing the errors that did exist. Interestingly, group 2 actually increased in productivity with their increased vigilance as indicated by the positive beta value. Therefore, for H5a the data analysis only supports the hypotheses for group 1. H5b was not supported by either group as vigilance decrement had no significant influence on productivity.

Application to Model

The regression analysis performed above was based directly on the theoretical model generated in chapter 2. The following illustration, Figure 4-1, summarizes the influence each construct had on subsequent constructs.

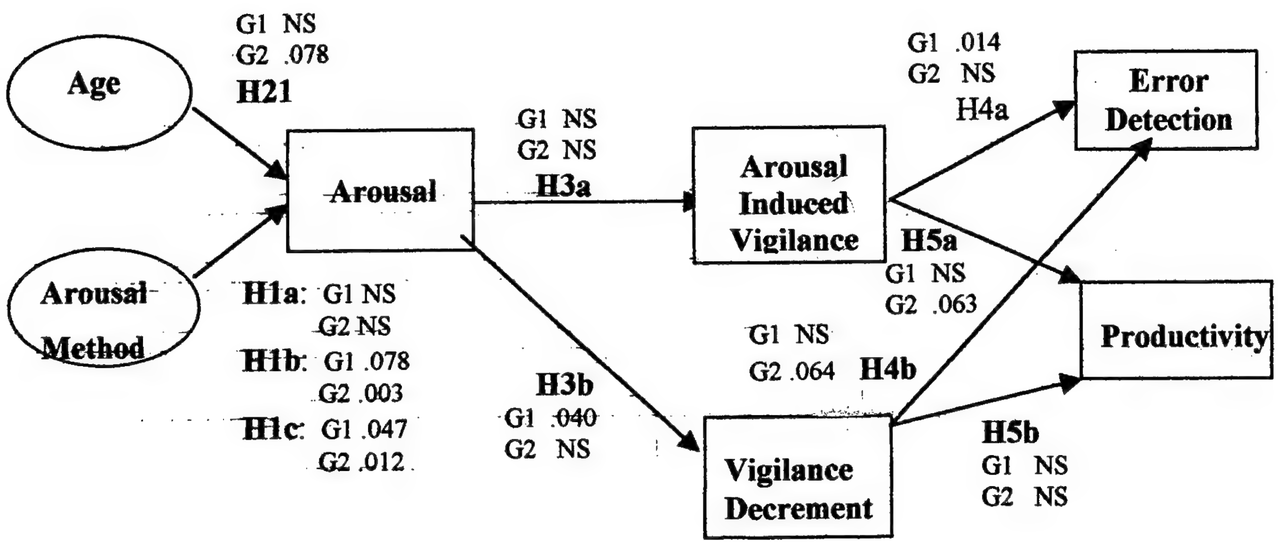


Figure 4-2: Weighted Theoretical model of Arousal-Vigilance Interaction

The illustration demonstrates how significant the support was for each hypothesis based upon the different groups. With the exception of H3a and H5b, each hypothesis received moderate to strong support from at least one of the two groups.

Summary

The data analysis conducted above indicated the influence each of the constructs had upon one another. Additionally, the results tended to support either in part or completely the hypotheses generated in chapter 2, with the exception of hypothesis 3. A discussion of these

results as well as complete review of the implications, applications, and limitations of this study will be discussed in chapter 5.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Introduction

The previous four chapters outlined the research question, explored previous research, developed new hypotheses and a theoretical model, designed an experiment, and collected and analyzed the data. This chapter will discuss the results of this study and compare them to previous work accomplished in the vigilance field. Additionally, the limitations of this study will be addressed. Finally, the application to the Air Force and areas of future study will be offered.

Observations

Hypothesis 1(a,b,c). The first hypothesis stated an expectation of a positive relationship between stimuli and arousal. For this study, H1b and H1c were both strongly supported by both groups at a moderate to high degree of significance (G1 = .078 and .047, G2 = .003 and .012). These findings are consistent with previous work accomplished on arousal (Blocher et al 1986; Tipples and Sharma 2000). What made this study unique was that it considered age as well as stimuli type. The regression analysis conducted in chapter 4 strongly indicated that the type of stimuli did matter for both the older group as well as for the younger group. The regression also indicated that for the older group, audio and visual combination stimuli was more effective than any of the signals individually, while for the younger group the visual stimuli alone was the most effective. This type of result is not precedented in previous research as few studies used a varied type of arousal mechanism (Mehrabian 1995). Nevertheless, hypotheses 1b and 1c were supported by the data.

The significance of these findings revolves around the distinction of method type when arousing a subject. Older subjects, while less significantly aroused then younger subjects overall, seemed to respond best to a combination of audio and visual signals. In contrast, the younger subjects responded better to visual signals. Both groups, however, did not respond to simple audio stimuli. These results indicate that system developers who are interested in arousing the system operators in cases of information warfare attacks must closely understand who the operators are and then apply the most effective means available. In short, effectiveness of arousal methods may depend upon the intended audience. In this case, age made a difference in arousability.

Hypothesis 2. The second hypothesis was closely related to the first and was primarily designed to see if age could impact or in some way limit arousal. Group 1 had no significant impact for age upon arousal. Group 2, however, found that age did have a significant negative influence (.078) on arousal. This result is in disagreement with the previous work of Dittmar and Warm (1993) and Pigeau and Angus (1995) who all found that the more age a subject had, the less they were able to be aroused. For this study, the data suggests that the younger group, whose age had a negative impact on arousal, may have been limited in their arousability by their age. Regardless, partial support for H2 was found in the data from group 2.

This finding suggests that the previous studies may not have considered the arousal method when concluding that age limits arousal. In light of the findings in H1b and H2c, it may stand to reason that stimuli type is more important in determining whether or not a subject will be aroused than the age of the subject. The regression model in Table 4-1 supports this concept in the sense that stimuli type was more significant in explaining arousal than age.

Hypothesis 3(a,b). For this study, arousal did not have any significant impact on vigilance for either group. This finding was unexpected as it contradicted many previous studies (Parasuraman and Davies 1984; Singh and Molloy 1993; Paus and Zatorre 1997). In each of these studies, some form of stimuli increased the arousal level within the subjects to a point were vigilance had been positively affected. In this study, arousal itself had no significant impact on vigilance, yet the stimuli itself did for group 2. In particular, the visual and audio-visual combination seemed to be the most effective in relation ship to vigilance. Therefore, while no support for H3a was detected, an encouraging discovery of the impact of stimuli type on vigilance was important.

Of greater value to vigilance research may have been the affect of arousal on vigilance decrement. While previous studies indicated arousal would affect vigilance, none discussed arousal's direct impact on vigilance decrement. Parasuraman and Davies suggested that arousal would impact vigilance levels but do little for vigilance decrement (1984). In this study, H3b posited that arousal would have a positive affect on decreasing the rate vigilance decrement, particularly over an extended period of reapplication. For group 1 this effect is suggested by the results of the regression analysis. Arousal significantly influenced (.040) the improvement in vigilance decrement. This result indicates that the vigilance decrement may be able to be averted, at least for short periods, if the right kind of arousal method is continuously reapplied to the subject.

Hypothesis 4(a,b). Consistent with previous work dating back to the first vigilance studies of N. H. Mackworth in 1950, this study found that vigilance had a significant (.014) affect on error detection, if only for the older group (Parasuraman and Davies 1984, Dittmar and Warm 1994). This result, although expected, was not as dramatic as hoped. Group 2, which had

the highest average detection rate, was not significantly influenced by vigilance. More important, however, may be the effect of the arousal-vigilance interaction upon error detection. Both groups experienced a positive influence (group 1: .013 and group 2: .076) upon error detection from the arousal-vigilance interaction factor. This finding may mean that artificially high states of vigilance, induced by arousal, will lead to improved error detection. Further research would be required to explore that possibility as the results for H3a indicated arousal had not impacted vigilance to any significant degree. Nevertheless, the data does suggest that support exists for H4a.

A second interesting facet of error detection was the impact of vigilance decrement. Hypothesis H4b suggested that improved rates of vigilance decrement might be able to directly affect error detection. For group 2, a modestly significant (.064) influence was exerted on error detection. Group 1, however, did not share this result. These findings signify that vigilance alone is not the only determinant of error detection. As a result, partial support for H4b is suggested by the regression analysis.

Hypothesis 5(a,b). It was speculated that productivity would be the casualty of increased arousal and vigilance (Biros 1998; Hackley and Valle-Inclan 1999; Mosier et al 1999). For group 2, higher vigilance did have a moderately significant (.063) negative impact on productivity. This study defined productivity as a combination of incorrect detects and time wasted on already detected errors. Group 1 experienced increases in the unproductive behaviors as their vigilance increased. Group 2, however did not have the same problem. In actuality, their higher states of vigilance actually improved, or at least maintained their level of productivity. Consequently, hypothesis 5a was only partially supported. Like H4a, when considering the interaction of arousal and vigilance, the effect on productivity changes. Group1

and group 2 both experienced a significant negative impact upon productivity from the arousal-vigilance interaction factor (.047 and .042 respectively). This result indicates that a decrease in productivity was tied to arousal induced vigilance, if only indirectly. The significance of this finding reflects the discoveries of past research in that efforts to produce higher vigilance and improved error detection are often accompanied by a decrease in productivity for the subject.

In addition to arousal and vigilance, vigilance decrement also may have impacted productivity. H4b proposed that improved vigilance decrement rates could positively affect productivity. For this study, no supporting evidence was available.

Summary. The subjects in groups 1 and 2 both appear to be influenced by arousal stimuli, although the type of stimuli most effective varied between groups. Also evidence exists to suggest arousal is not as influenced by age as it by arousal method. Further evidence failed to support the possibility of arousal directly influencing vigilance and only moderate support exists to suggest that it influences vigilance decrement. Similarly, vigilance and vigilance decrement only moderately influence error detection and productivity, while the interaction of arousal and vigilance appears to have significantly impacted both error detection and productivity.

Limitations

Arousal Measuring Methods. The unexplained lack of influence arousal had on vigilance may reflect a problem in the reporting of arousal by the subjects. Although the survey technique used has been proven in previous studies, the most effective way to measure arousal is through medical testing equipment such as the EKG or heart monitor (Hackley and Valle-Inclan 1999; Paus and Zatorre 1997). Such equipment can measure the physiological changes within

the human body and thus eliminate the need to rely upon the subject to "remember" and then quantify how he or she felt.

Training. A second limitation of this study included the training time available for each subject to become familiar with the DDD system. In reality an operator would be expected to thoroughly know and understand the system he or she is operating. For this experiment, each subject received 30 minutes of classroom instruction and 20 minutes of hands-on time with the system. Survey results reveal that the subjects claimed to have understood their tasks and how to use the system, but that is far from expecting them to be proficient. A subject who thoroughly understands the system in use may be more likely to detect any potential problems.

Laboratory Setting. The third limitation for this study was the laboratory setting. Although every possible measure was taken to make the simulation as real as possible, the fact remains that the experiment took place within controlled settings. The subjects could not feel the pressures of a wartime exercise or the possible consequences of incorrect decisions. The use of a scoring system may have mitigated these problems, but a complete duplication of a real world scenario was not within the time and means of this study.

Physical Capabilities. The final limitation of this study may have been the lack of testing for sensory perception within the subjects. This study relied upon the subjects being able to hear and see the arousal signals. Given the range in ages of the subjects, it may have been possible that some subjects were not able to detect the arousal cues due to poor eyesight or hearing.

Implications for the Air Force

This study was conducted with sponsorship from the Air Force Office of Scientific Research and was designed to explore methods for improving defenses against information

warfare attacks. In this light, the implications for the Air Force primarily revolve around information warfare tactics and defenses, but could be extended to any arena using automated decision aids.

The first implication is for system designers. While the study did not show that arousal could affect vigilance, it did give strong indications that some level of stimuli did have an affect on vigilance. System designers should consider incorporating warning signals within the system that can be selectively initiated in the event of an information warfare attack. Such a signal could give the desired "heads-up" effect that can help operators remain vigilant and detect data manipulations before they can do any harm.

The second implication is for information warfare defenses. This research indicates the possibility for command and control system operators to experience vigilance decrement over time. As a result, information warfare operators should explore methods for improving the chance that errors caused by data manipulation would be detected. One aspect of this study looked at age and issues. In an environment where information technology is the primary means of obtaining decision-making data, the younger group seemed naturally more adept at detecting errors. There may be many reasons for this phenomenon to include a predisposition for interpreting computer technology due to a greater familiarity with computers or, as this study seems to indicate, a naturally higher state of vigilance. Either way, the results of this study suggest that youthfulness may help in error detection. However, on a note of encouragement, if older personnel are required to operate the systems, the warning stimuli did seem to improve their ability to detect errors.

Recommendations for Future Research

This study explored a very limited area of vigilance and arousal research. Many other aspects of vigilance-arousal interaction remain open to study. First, one of the key issues surrounding arousal is the length of time arousal is effective. The point at which the problem of habituation occurs is not well addressed in the literature on arousal. Similarly, the proper frequency of arousal application may play a role in how effective arousal is. For this study a stimuli, if applied, was applied once every 200 seconds. Variations of that may produce different results. Finally, it may be interesting to explore the different arousal effects on gender. Dittmar and Warm have conducted several studies on vigilance and gender and have suggested a very possible link between arousal cues and gender (1993). Research into gender differences could answer many questions on how vigilance can be affected by arousal techniques. Given the findings concerning arousal-vigilance interaction, there is significant reason to believe that future research on arousal and vigilance may yield important results.

Other areas of potential study include the interaction of arousal and confidence on error detection. Evidence from this study suggests an inverse relationship exists. While it was not a focus of this experiment, confidence levels of the subjects were collected for every decision they made. Analysis of the confidence levels seemed to indicate that when arousal and vigilance was high, the subject's confidence in their decision was low. A study could be developed to explore the implications of such a relationship.

Finally, the best future study in the arousal-vigilance research would include a multiple measure of arousal. This study may have been limited on the ability to accurately assess a subject's arousal level. The use of physiological measures as well as self-reporting

questionnaires may prove to be valuable for future studies of arousal. Once accurately measured, the true impact of arousal may be found.

Conclusion

The results of this study indicate that arousal does have an impact on vigilance. In an information warfare data manipulation environment, the ability to detect errors is of utmost importance. Arousal–vigilance research may provide one avenue for containing the threat of data manipulation.

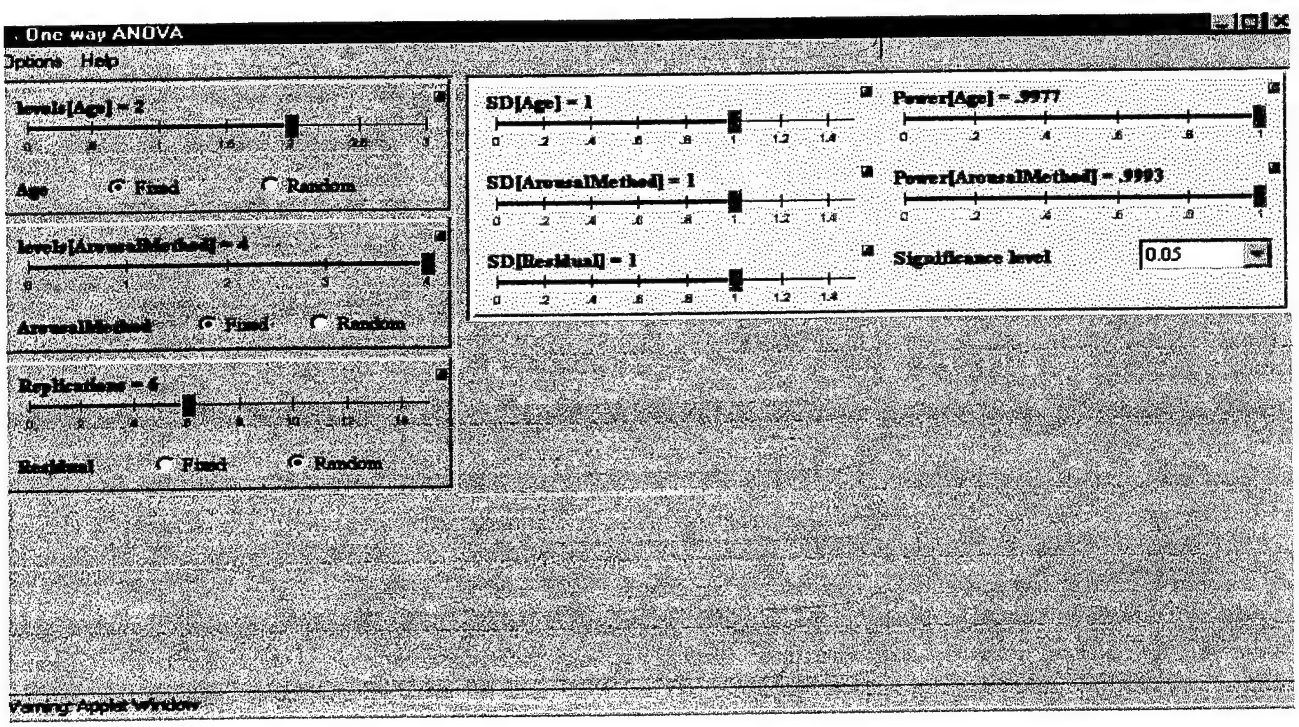
Appendix A: Power Analysis

For this experiment the following 2-4 Matrix describes the various factors and levels:

Older Age	Visual	Audio	Visual/ Audio	No Cue
Younger Age	Visual	Audio	Visual/ Audio	No Cue

Using a Power Analysis software created by Dr. Russ Lenth at the University of Iowa, a power analysis was performed to determine the proper number of subjects required to make this study statistically valid. The following sections are the results of the analysis.

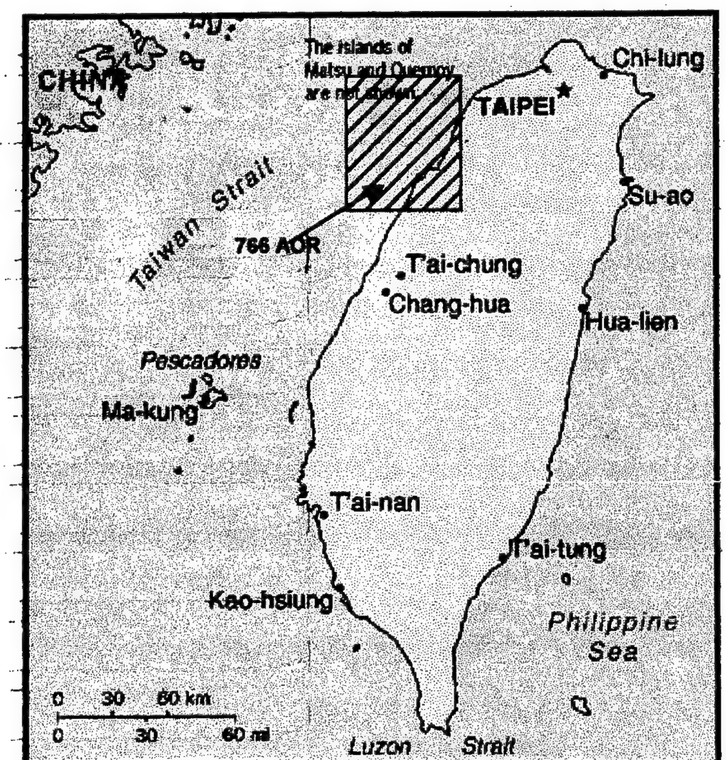
These two charts depict the expected power of a sample size of 6 per cell (above matrix) for a total number of 48 subjects. At a significance level of .05, the power for age and arousal method is .9977 and .9993 respectively (assuming a standard deviation of 1).



Appendix B: Experiment Scenario

BACKGROUND:

You are the air defense commander for 766th Air Defense Unit deployed in Northwest Taiwan. The 766th is a joint air defense unit that integrates tactical ground radar units and surface-to-air missile defense units into a single weapon system. The ADU is a deployed arm of the Air Operation Center and has data connectivity with the AOC, remote radar sites, and remote SAM sites.



THE PRESENT: You have just received the crew changeover briefing where you received the standard mission briefing, Intelligence briefing, and the Rules of Engagement briefing. The following is a summary of the information you received:

MISSION: Defend the assigned air space against any suspected hostile aircraft. The 766^{th} is one of several air defense units dispersed along the coast of Taiwan. You are responsible for air surveillance, track identification, and weapon interdiction. The commander of the 766^{th} is also responsible for assigning a confidence level to all track information and forwarding that information to the Air Operation Center.

INTEL BRIEF:

In early July, the Chinese government declared it does not recognize the independence of Taiwan, as declared by the Taiwanese government this past June.

In response to this declaration, Taiwan requested and received military support from the United States. This support consisted of two naval battle groups, the regional deployment of 120 fighter and support aircraft, and the local deployment of 5 new Air Defense Units with remotely operated radar and SAM sites.

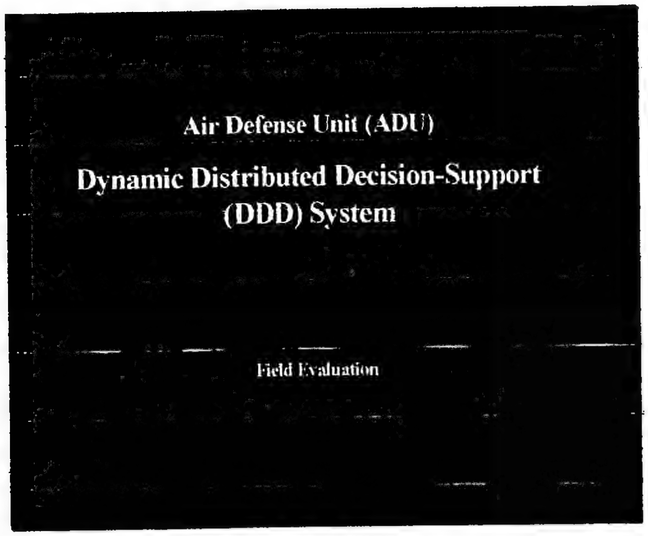
The deployment was completed in late August. Following this deployment, China threated that if allied forces were not withdrawn by the first of September then China would reserve the option for a military response. Intel sources and satellite imagery indicate a massive Chinese air assault is imminent.

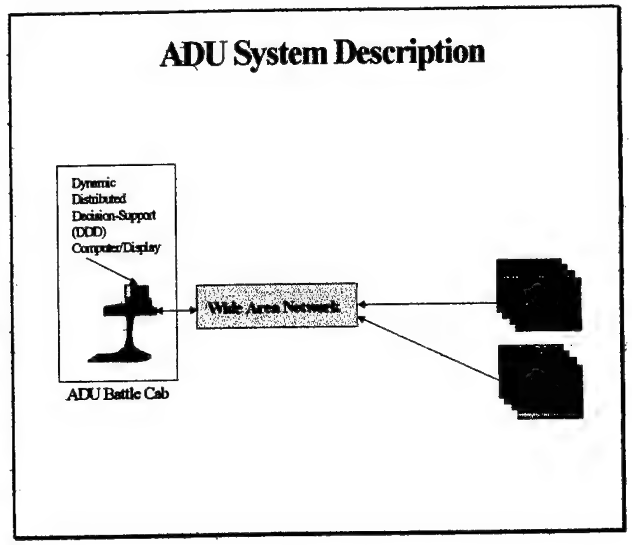
Intel also reports that the Peoples Republic of China's Information Warfare Force (IWF) have been probing the U.S. forces Wide Area Network. The IWF technology is thought to include some of the most advanced network attack and information manipulation systems in the world. The Chinese have recently demonstrated a successful Information Warfare attack, known

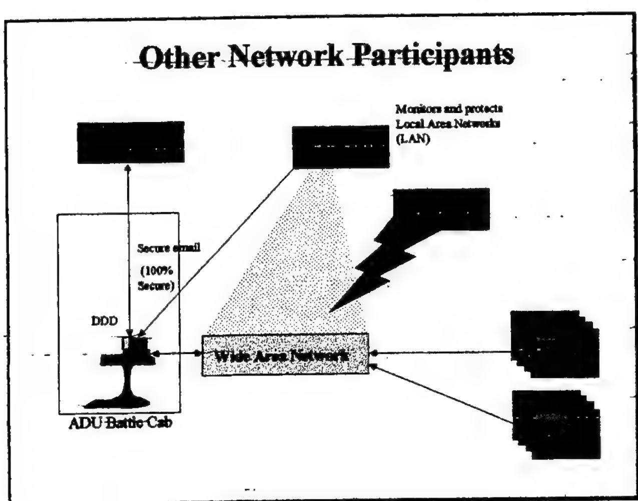
as Strategic Information Manipulation (SIM), against the Taiwanese government. SIM is a technique whereby the network is covertly accessed and real-time tactical or strategic information is manipulated in order to confuse or spoof the enemy

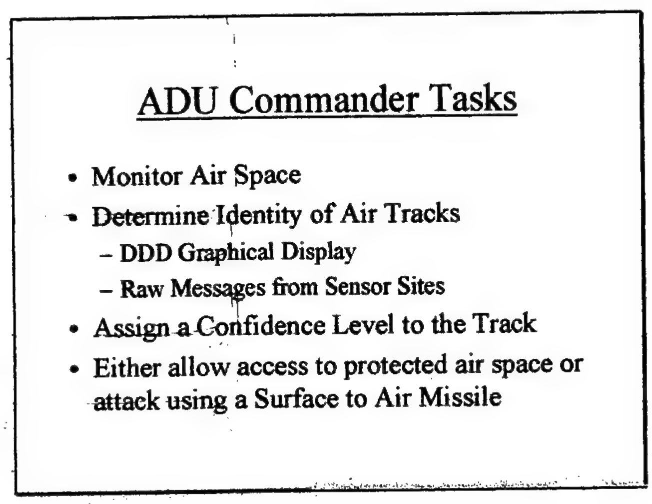
RULES OF ENGAGEMENT: By the order of the President of the United States, all US military forces are authorized to use deadly force to interdict hostile aircraft from entering Taiwanese airspace.

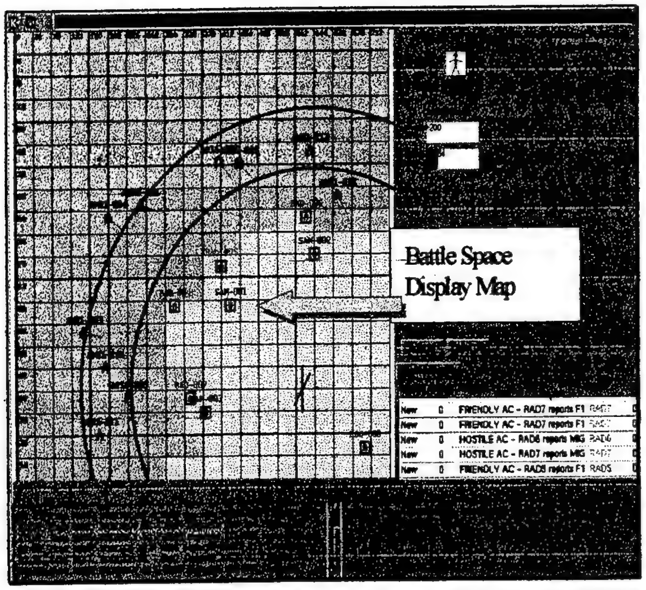
Appendix C: Training Slides



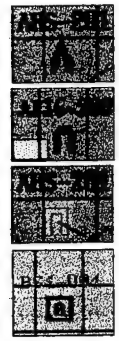




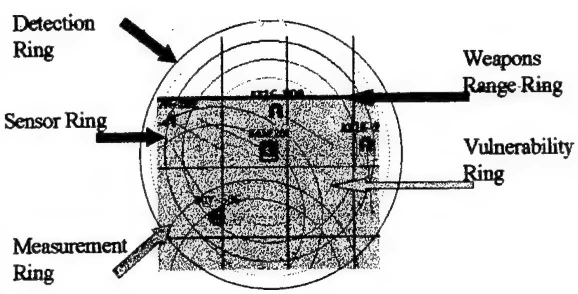




Display Icons



Air Track Sensor/Weapon Ranges



Score System

	Confidence Level					
	0	1	2	3	4	5
Shoot Enemy	N/A	20	40	70	110	160
Shoot Friendly	N/A	-40	-90	-160	-250	-500

If an enemy enters the protected air space, you will **lose 1 point for each second** it remains in the air space.

Hands On Demonstration

Practice Simulation

Evaluation

BREAK

FULL SIM

Question and Answer Time

Appendix D: Questionnaires

Informed Consent Form

<u>Study Overview</u>

Welcome to the experiment. The following is a general description of the study and a reminder of your rights as a potential subject. As in any study, your participation is completely voluntary. If now, or at any point during the study, you decide that you do not want to continue participating, please let the experimenter know and you will be dismissed without penalty. Also, please remember that your name will not be associated with any of the information that you provide during the study. All of the information you provide is absolutely anonymous and confidential.

In this study, you will be working as part of a group to complete a mission objective. You will also be asked to complete two questionnaires during the study. You will first be given a questionnaire to complete, then following the training, you will be given the second second questionnaire to complete. The experimenter will give you more specific instructions later in the study. If you have any questions or concerns at this time, please inform the experimenter.

<u>For further information</u>

The Air Force Institute of Technology faculty members responsible for conducting this research are Maj. David Biros. He would be happy to address any of your questions or concerns regarding this study. Maj. Biros can be reached at 255-3636 ext 4578.

If you would like to participate in this study, please sign in the space provided. Your signature indicates that you are aware of each of the following: 1) the general procedure to be used in this study, 2) your right to discontinue participation at any time, and 3) you and your name will not be associated with any of the information you provide.

Printed Name: ______________________

Signature: ___________________________ Date: _________________

Survey 1

Participant Information Sheet

Participant # ______

INSTRUCTIONS

This is a short two-part survey to determine the demographic information of the participants in this research as well as their experience level with computer systems. The data collected will be used to aid in the evaluation of the results of the simulation. All information provided will be kept confidential and will not be able to be traced back to the participant.

SECTION 1 – Demographic Information

1. Age _______
2. Rank _________ Service (USAF, Army, Navy) ____________
3. AFSC ____
4. Number of years served in current AFSC __________
5. Total number of years served in the military _________
6. Highest Level of Education (circle one): High School, Undergraduate, Graduate, Doctoral
7. Operational experience in Combat/Hostile Duty Location (yes/no) ___________

SECTION II – Computer Experience an Attitudes (Circle One)

1. Are you currently, or have you ever, worked in a computer communications position?	Y	N
2. Do you consider yourself to be knowledgeable about computers?	Y	N
3. Are you familiar with how a computer network operates?	Y	N
4. Are you familiar with any programming languages?	Y	N

5. Which computer programs do you use on a frequent basis ___________________________

____

____

6. Do you like to use computers to conduct work? Y N

7. Do you feel comfortable with the role computers play in today's Air Force? Y N

   Why or why not?

   ____

   ____

   ____

SECTION III: Computer Beliefs

Please answer all of the questions below. Use the scale provided and enter the number that best matches your beliefs.

1 = Strongly Disagree; 2 = Disagree; 3 = Somewhat Disagree; 4 = No opinion

5 = Somewhat Agree; 6 = Agree; 7 = Strongly Agree

1. ________ If you initiate a task for the average computer system to perform, the computer system will finish it correctly.

2. ________ I believe that most computer systems are consistent.

3. ________ Most computer systems are reliable.

4. ________ I believe that most computer systems are technically competent.

5. ________ I feel I can depend on most computer systems.

6. ________ I can trust most computer systems.

Survey 2 Participant #:________

INSTRUCTIONS

The information you provide will be kept confidential. In addition, your identity will not be linked to this data. The information collected from this form will be used to help evaluate the ADU system and training program.

Definition: ***Command and Control (C2)***

Command and control (C2) describes the basic job of the military battle commander. The battle commander is responsible for directing military forces to accomplish military objectives against an adversary. In your case, this is air space defense using surface-to-air missiles. C2 objectives often result in material damage and/or human casualties to both the adversary and friendly forces.

Participant Questionnaire

Please answer all of the questions below. Use the scale provided and enter the number that best matches your beliefs.

1 = Strongly Disagree; 2 = Disagree; 3 = Somewhat Disagree; 4 = No Opinion; 5 = Somewhat Agree; 6 = Agree; 7 =Strongly Agree

1. ________ In a command and control environment like described in the scenario brief, I believe computers can be relied upon to help commanders make operational decisions.

2. ________ I feel I can depend on computer systems to provide timely and accurate information to battle commanders in a combat situation.

3. ________ In a command and control setting like the one described in the scenario, I feel that I can adequately trust information received from most computer systems.

4. ________ I believe that most computer systems used in deployable battle cabs are secure enough to trust in combat situations.

5. ________ I feel most computer systems used in command and control units are dependable.

Survey 3 Participant #:________

INSTRUCTIONS

The information you provide will be kept confidential. In addition, your identity will not be linked to this data. The information collected from this form will be used to help evaluate the ADU computer system and training program.

Please answer all of the questions below. Use the scale provided and enter the number that best matches your beliefs.

1 = Strongly Disagree; 2 = Disagree; 3 = Somewhat Disagree; 4 = No Opinion; 5 = Somewhat Agree; 6 = Agree; 7 =Strongly Agree

1. ________ The DDD computer system is predictable.
2. ________ The DDD computer system is consistent.
3. ________ The DDD computer system is technically competent.
4. ________ The DDD computer system has integrity.
5. ________ The DDD computer system is reliable.
6. ________ The DDD computer system is dependable
7. ________ I can trust the DDD computer system.

Training Evaluation

Please circle the correct answer:

1. The role of the Network Security Force is to ________
   a. Monitor the network only
   b. Protect the network only
   c. Monitor and Protect the network
   d. None of the above

2. An upside "V" shaped icon that is colored red represents what type of track? _______
   a. Friendly
   b. Hostile
   c. Unknown
   d. None of the above

3. Which of the following are Information Warfare tactics? _________
   a. Denial of Service
   b. Information Manipulation
   c. Hacking
   d. All of the above

4. The main components of the ADU are ____________
   a. The DDD computer system, the WAN, and the sensor sites
   b. The DDD computer system and the Network Security Forces
   c. The Network Security Forces, the DDD computer system, and the WAN
   d. None of the above

5. Track identity is automatically determined by DDD. A secondary means by which you can verify the track identity is to _______
   a. Send a request to the AOC
   b. Read incoming messages from the sensor sites.
   c. None of the above
   d. All of the above

Survey 4

Post Simulation Evaluation Sheet | Participant # ______

INSTRUCTIONS

This is a short survey to assess the participant's reaction to the simulation. Please circle the correct answer.

1. Were the instructions clear and understandable? Y N
2. Was the simulation easy to understand? Y N
3. Was the training sufficient for you to play the game? Y N
4. Did you encounter any difficulties in following the instructions for the game? Y N
5. Was the game's operations tempo too fast? Y N
6. Was the scenario realistic? Y N
7. Arousal is defined as a heightened state of alertness due to an external stimuli. On a scale of 1 to 7, please state the level of arousal you felt when alerted to a network attack.

   Lowest Highest

   1 2 3 4 5 6 7

8. Did the warnings cause you to alter your strategies? Y N
9. Did you find the warnings credible? Y N
10. Did you notice any errors in the simulations? Y N

    If so, how many? ________

Thank you for participating in this research. Your inputs are extremely valuable.

Appendix E Statistical Analysis Tables

Descriptive Statistics

Groups 1 and 2	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	34.33	158.483	0.63	0.33	4.86	0.33	3.77	19.22
Std Err	0.62	4.04958	0.03	0.03	0.09	0.01	0.16	1.00
Median	30.00	168	1.00	0.00	5.00	0.33	3.00	15.00
Mode	27.00	120	1.00	0.00	5.00	0.25	3.00	15.00
Std Dev	8.72	57.9812	0.49	0.47	1.23	0.18	2.26	14.03
Sam Var	76.07	3361.82	0.24	0.22	1.52	0.03	5.09	196.95
Kurtosis	-0.64	-0.3773	-1.74	-1.51	-0.41	-0.57	-0.40	0.61
Skew	0.73	-0.4421	-0.52	0.71	-0.53	0.18	0.62	1.06

Group 1-1	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	39.39	40.5	0.44	0.39	4.56	0.14	1.44	6.94
Std Err	1.15	0.90116	0.12	0.12	0.23	0.02	0.18	0.95
Median	40.00	41	0.00	0.00	4.00	0.17	2.00	8.00
Mode	42.00	42	0.00	0.00	4.00	0.17	2.00	8.00
Std Dev	4.89	3.8233	0.51	0.50	0.98	0.10	0.78	4.04
Sam Var	23.90	14.6176	0.26	0.25	0.97	0.01	0.61	16.29
Kurtosis	3.14	0.95816	-2.20	-1.99	-0.92	0.08	-0.45	-0.65
Skew	-0.75	0.61099	0.24	0.50	0.24	0.42	-1.03	-0.59

Group 1-2	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	43.11	86.2105	0.47	0.47	3.95	0.22	2.47	9.68
Std Err	1.73	3.4536	0.12	0.12	0.30	0.02	0.31	1.48
Median	42.00	84	0.00	0.00	4.00	0.25	3.00	9.00
Mode	36.00	72	0.00	0.00	3.00	0.25	3.00	12.00
Std Dev	7.53	15.0539	0.51	0.51	1.31	0.10	1.35	6.47
Sam Var	56.65	226.62	0.26	0.26	1.72	0.01	1.82	41.89
Kurtosis	-0.29	-0.2867	-2.24	-2.24	-1.14	-0.43	-1.38	-0.24
Skew	0.91	0.90827	0.11	0.11	0.27	-0.72	-0.39	0.47

Group 1-3	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	45.88	137.654	0.46	0.54	4.35	0.28	3.12	13.31
Std Err	0.96	2.87907	0.10	0.10	0.28	0.02	0.27	1.38
Median	44.00	132	0.00	1.00	5.00	0.25	3.00	15.00
Mode	51.00	153	0.00	1.00	5.00	0.25	3.00	18.00
Std Dev	4.89	14.6804	0.51	0.51	1.44	0.12	1.37	7.01

Sam Var	23.95	215.515	0.26	0.26	2.08	0.01	1.87	49.18
Kurtosis	-1.96	-1.9605	-2.14	-2.14	-0.78	-0.39	-0.87	-1.18
Skew	0.00	0.00232	0.16	-0.16	-0.75	-0.43	0.08	0.11

Group 1-4	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	41.28	165.12	0.60	0.36	4.88	0.25	2.56	12.84
Std Err	1.04	4.16666	0.10	0.10	0.25	0.02	0.14	1.08
Median	40.00	160	1.00	0.00	5.00	0.25	3.00	15.00
Mode	35.00	140	1.00	0.00	6.00	0.25	3.00	18.00
Std Dev	5.21	20.8333	0.50	0.49	1.27	0.08	0.71	5.38
Sam Var	27.13	434.027	0.25	0.24	1.61	0.01	0.51	28.97
Kurtosis	-1.64	-1.6392	-1.98	-1.76	-1.44	2.07	5.83	-0.60
Skew	-0.02	-0.0194	-0.43	0.62	-0.56	-1.42	-2.11	-0.65

Group 2-1	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	25.67	128.333	0.62	0.38	4.19	0.39	3.48	14.10
Std Err	0.32	1.59364	0.11	0.11	0.25	0.05	0.32	1.46
Median	26.00	130	1.00	0.00	4.00	0.42	4.00	12.00
Mode	24.00	120	1.00	0.00	3.00	0.42	5.00	12.00
Std Dev	1.46	7.30297	0.50	0.50	1.17	0.22	1.47	6.70
Sam Var	2.13	53.3333	0.25	0.25	1.36	0.05	2.16	44.89
Kurtosis	-0.35	-0.3492	-1.91	-1.91	-1.30	-1.47	-1.46	0.51
Skew	0.54	0.53995	-0.53	0.53	0.43	0.08	-0.42	0.79

Group 2-2	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	28.40	170.4	0.73	0.20	4.60	0.22	2.40	11.40
Std Err	0.29	1.73699	0.12	0.11	0.19	0.02	0.24	1.22
Median	28.00	168	1.00	0.00	5.00	0.25	3.00	15.00
Mode	28.00	168	1.00	0.00	5.00	0.25	3.00	15.00
Std Dev	1.12	6.72734	0.46	0.41	0.74	0.09	0.91	4.72
Sam Var	1.26	45.2571	0.21	0.17	0.54	0.01	0.83	22.26
Kurtosis	0.38	0.37826	-0.73	0.90	1.32	2.04	2.36	0.98
Skew	0.11	0.11226	-1.18	1.67	-1.63	-1.43	-1.63	-1.24

Group 2-3	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	27.80	194.634	0.78	0.20	5.27	0.46	5.59	29.56
Std Err	0.20	1.38756	0.07	0.06	0.11	0.02	0.35	1.99
Median	28.00	196	1.00	0.00	5.00	0.50	7.00	30.00

Mode	28.00	196	1.00	0.00	5.00	0.50	3.00	15.00
Std Dev	1.27	8.88469	0.42	0.40	0.71	0.16	2.27	12.72
Sam Var	1.61	78.9378	0.18	0.16	0.50	0.03	5.15	161.85
Kurtosis	-0.90	-0.8963	-0.02	0.58	-0.87	0.30	-1.07	-1.08
Skew	0.23	0.23169	-1.41	1.60	-0.44	-0.46	-0.55	-0.25

Group 2-4	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	28.70	229.6	0.75	0.23	6.10	0.48	6.18	37.75
Std Err	0.46	3.71497	0.07	0.07	0.11	0.02	0.33	2.20
Median	28.50	228	1.00	0.00	6.00	0.50	6.00	35.00
Mode	32.00	256	1.00	0.00	6.00	0.42	5.00	42.00
Std Dev	2.94	23.4956	0.44	0.42	0.67	0.10	2.09	13.90
Sam Var	8.63	552.041	0.19	0.18	0.45	0.01	4.35	193.12
Kurtosis	-1.84	-1.8428	-0.59	-0.14	-0.68	11.74	0.49	0.10
Skew	-0.08	-0.079	-1.20	1.37	-0.12	-2.57	-0.44	-0.07

Group 1	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	42.65	114.477	0.50	0.44	4.45	0.23	2.48	11.09
Std Err	0.65	5.261	0.05	0.05	0.14	0.01	0.13	0.68
Median	42.00	126	0.50	0.00	5.00	0.25	3.00	10.00
Mode	40.00	153	0.00	0.00	6.00	0.25	3.00	18.00
Std Dev	6.06	49.3526	0.50	0.50	1.30	0.11	1.23	6.35
Sam Var	36.67	2435.68	0.25	0.25	1.70	0.01	1.52	40.31
Kurtosis	-0.10	-1.1722	-2.05	-1.99	-0.99	-0.50	-0.06	-0.70
Skew	0.30	-0.2488	0.00	0.23	-0.39	-0.34	0.07	0.20

Group 2	Age	Age-Stimuli Int	% Cor Det	Prod	Arous	Vig Dec	Vig	Arous-Vig Int
Mean	27.80	191,581	0.74	0.24	5.27	0.42	5.00	27.26
Std Err	0.21	3.59416	0.04	0.04	0.10	0.02	0.22	1.42
Median	28.00	196	1.00	0.00	5.00	0.42	5.00	25.00
Mode	27.00	196	1.00	0.00	6.00	0.50	3.00	15.00
Std Dev	2.26	38.8767	0.44	0.43	1.06	0.17	2.37	15.33
Sam Var	5.12	1511.4	0.20	0.18	1.13	0.03	5.60	234.88
Kurtosis	-0.75	-0.5152	-0.85	-0.48	-0.16	-0.22	-0.96	-0.73
Skew	0.35	-0.1556	-1.08	1.24	-0.53	-0.49	-0.02	0.36

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Vita

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14. ABSTRACT

This study focused on improving viglance performance through developing methods to arouse subjects to the possibility of errors in a data manipulation information warfare attack. The study suggests that by continuously applying arousal stimuli, subjects would retain initially high vigilance levels thereby avoiding the vigilance decrement phenomenon and improving error detection. The research focused on which methods were the most effective as well the impact of age upon the arousability of the subjects. Further the implications of vigilance and vigilance decrement for correct detections as well as productivity were explored.
The study used a simulation experiment to provide a vigilance task in an reality-based information warfare environment. The results of the study suggest that stimuli type and age do impact arousal, although stimuli type had the greater effect. Also, moderate support was found to indicate that arousal does affect vigilance and vigilance decrement. However, the final analysis revealed that it was the arousal-vigilance interaction that had the greatest impact on correct detection and productivity.

15. SUBJECT TERMS

Vigilance, Arousal, Vigilance Decrement, Productivity, Error Detection

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